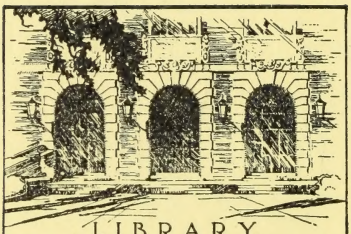

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OF THE

LIVERPOOL ENGINEERING SOCIETY.

VOL. XXV.

THIRTIETH SESSION.

EDITED BY

R. C. F. ANNETT, ASSOC. INST. C.E.,

Honorary Secretary.

LIVERPOOL:

PUBLISHED BY THE SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

1904.

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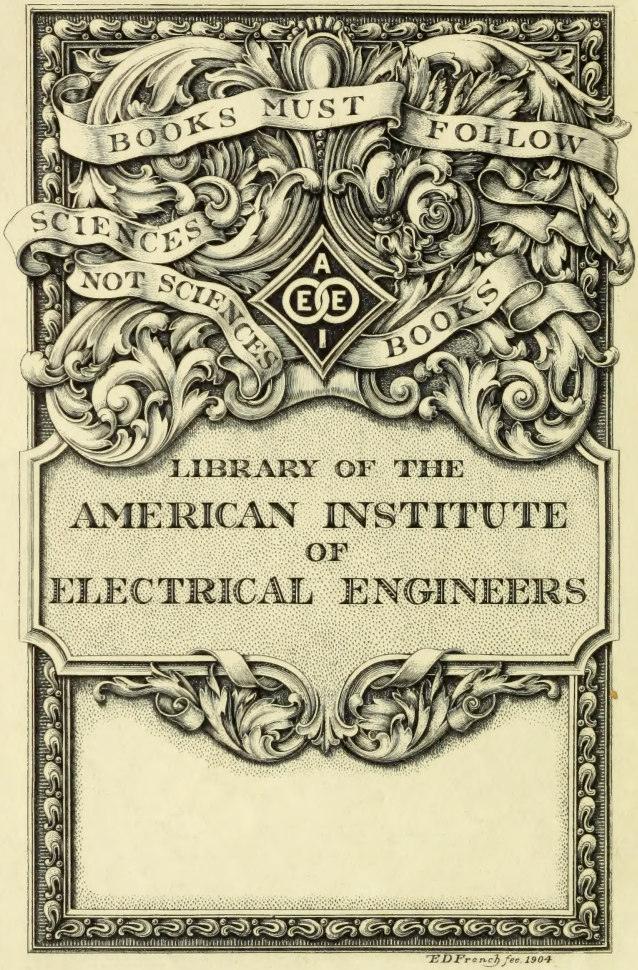
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The Society as a body is not responsible for the statements made or the opinions expressed in this Volume.

LIVERPOOL ENGINEERING SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

XXX SESSION.—1903-1904.

(From the 4th November, 1903, to the 27th April, 1904.)

COUNCIL.

In accordance with Rule V, the following Council commenced its duties on the first Wednesday in November, 1903.

President.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.

Vice-Presidents.

FRANK E. PRIEST, M. Inst. C.E.

J. RENEY SMITH, M.I. Mech. E., M.I.N.A.

Members of Council.

MALCOLM BLAIR.

ROBERT BRODIE, M. Inst. C.E.

WILLIAM BRODIE, Assoc. M. Inst. C.E.

W. J. WILLETT BRUCE, R.N.R.

FRANCIS E. COOPER, Assoc. M. Inst. C.E.

S. B. COTTRELL, M. Inst. C.E., M.I. Mech. E.

THOMAS DUNCANSON, M. Inst. C.E.

A. F. FOWLER, M. Inst. C.E., M.I. Mech. E.

H. S. HELE-SHAW, LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M.I. Mech. E., F.R. Met. Soc.

A. J. MAGINNIS, M. Inst. C.E., M.I.N.A., M.I. Mar. E.

HENRY H. WEST, M. Inst. C.E., M.I.N.A., M.I. Mech. E.

ARTHUR R. T. WOODS, M.I.N.A.

Past-Presidents.

In accordance with Rule IV, the following Past Presidents are ex-officio members of Council for five consecutive years after their retirement from Office.

JOHN A. BRODIE, Wh. Sc., M. Inst. C.E., M.I. Mech. E., 1898-1899.

A. BROMLEY HOLMES, M. Inst. C.E., M.I.E.E., 1899-1900.

JOHN A. F. ASPINALL, M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst., 1900-1901.

ARTHUR MUSKER, M. Inst. C.E., M.I. Mech. E., 1901-1902.

ERNEST S. WILCOX, M. Inst. C.E., 1902-1903.

Honorary Solicitor.

ERNEST W. PIERCE,
Deputy Town Clerk, Municipal Buildings, Liverpool.

Honorary Librarian.

REGINALD W. ARMISTEAD,
11, Derwent Drive, Liscard, Cheshire.

Honorary Treasurer.

COARD S. PAIN, Assoc. Inst. C.E., F.S.I.,
14, North John Street, Liverpool.

Honorary Secretary.

R. C. F. ANNETT, Assoc. Inst. C.E.,
4, Buckingham Avenue, Sefton Park, Liverpool.

NOTE.—In accordance with Rule V. the above Council continues in Office until the first Wednesday in November, 1904.

LIVERPOOL ENGINEERING SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

XXXI SESSION.—1904-1905.

(From the 2nd November, 1904, to the 26th April, 1905.)

COUNCIL.

In accordance with Rule V, the following Council will commence its duties on the first Wednesday in November, 1904.

President.

FRANK E. PRIEST, M. Inst. C.E.

Vice-Presidents.

J. RENEY SMITH, M.I. Mech. E., M.I.N.A.

A. F. FOWLER, M. Inst. C.E., M.I. Mech. E.

Members of Council.

EDWARD ALLEN, M.I. Gas E.

J. B. BREW.

ROBERT BRODIE, M. Inst. C. E.

WILLIAM BRODIE, Assoc. M. Inst. C.E.

W. J. WILLETT BRUCE, R.N.R.

FRANCIS E. COOPER, Assoc. M. Inst. C.E.

THOMAS DUNCANSON, M. Inst. C.E.

ALARIC HOPE, Assoc. M. Inst. C.E., A.M.I. Mech. E.

WILLIAM E. MILLS.

HENRY H. WEST, M. Inst. C.E., M.I.N.A., M.I. Mech. E.

H. W. WILSON, A.M.I.E.E.

ARTHUR R. T. WOODS, M. I. N. A.

Past-Presidents.

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A. BROMLEY HOLMES, M.Inst.C.E., M.I.E.E., 1899-1900.

JOHN A. F. ASPINALL, M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst., 1900-1901.

ARTHUR MUSKER, M. Inst. C.E., M.I. Mech. E., 1901-1902.

ERNEST S. WILCOX, M. Inst. C.E., 1902-1903.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E., 1903-1904.

Honorary Solicitor.

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Deputy Town Clerk, Municipal Buildings, Liverpool.

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R. C. F. ANNETT, Assoc. Inst. C.E.,
4, Buckingham Avenue, Sefton Park, Liverpool.

NOTE.—In accordance with Rule V, the above Council continues in Office until the first Wednesday in November, 1905.

LIVERPOOL ENGINEERING SOCIETY.

Past Presidents of the Society.

(1.)	1875-76 / 1877	C. Henry Graham Smith, Assoc. M. Inst. C.E.	(Died 9th Sept., 1884). See Memoir in Vol. LXXVIII. Proc. Inst. C.E.
(2.)	1878	Robinson Souttar, M.P., M.A., B.C.L. Oxon.	
(3.)	1879	M. E. Yeatman, M.A. Cantab., M. Am. Soc. C.E.	
(4.)	1880	Alexander Ross, M. Inst. C.E.	
(5.)	1881	Alfred Holt, M. Inst. C.E.	
(6.)	1882	Frank B. Salmon, M.I. and S. Inst.	
(7.)	1883	Henry Bramall, M. Inst. C.E.	
(8.)	1884	R. Ratsey Bevis, Junr., M. Inst. C.E.	
(9.)	1885	William E. Mills.	
(10.)	1886	Coard S. Pain, Assoc. Inst. C.E., F.S.I.	
(11.)	1887	John J. Webster, M. Inst. C.E.	
(12.)	1888	Chas. H. Darbishire, J.P., Assoc. M. Inst. C.E.	
(13.)	1889-90	Henry H. West, M. Inst. C.E., M. I. N. A., M. I. Mech. E.	
(14.)	1890-91	Ferdinand Hudleston, M. Inst. C.E.	
(15.)	1891-92	John T. Wood, M. Inst. C.E.	
(16.)	1892-93	Robert E. Johnston, M. Inst. C. E.	
(17.)	1893-94	H. Percy Boulnois, M. Inst. C.E., F.S.I.	
(18.)	1894-95	H. S. Hele-Shaw, LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M. I. Mech. E., F.R. Met. Soc.	
(19.)	1895-96	Arthur J. Maginnis, M. I. N. A., M. I. Mar. E.	
(20.)	1896-97	S. B. Cottrell, M. Inst. C.E., M.I. Mech. E.	
(21.)	1897-98	George Farren, J.P., M. Inst. C.E., F.R.S.S.	(Died 10th April, 1901). See Memoir in Proc. Inst. C.E.
(22.)	1898-99	John A. Brodie, Wh. Sc., M. Inst. C.E., M.I. Mech. E.	
(23.)	1899-00	A. Bromley Holmes, M. Inst. C.E., M.I.E.E.	
(24.)	1900-01	John A. F. Aspinall, M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst.	
(25.)	1901-02	Arthur Musker, M. Inst. C.E., M.I. Mech. E.	
(26.)	1902-03	Ernest S. Wilcox, M. Inst. C.E.	
(27.)	1903-04	Thomas L. Miller, M. Inst. C.E., M.I. Mech. E., M.I.E.E.	

Mr. THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

President of the Liverpool Engineering Society,

XXX Session—1903-1904.

LIVERPOOL ENGINEERING SOCIETY.

REPORT.—XXX SESSION.

1903-1904.

(From 4th November, 1903, to 27th April, 1904.)

President:—THOMAS L. MILLER,

M. Inst. C.E., M.I. Mech. E., M.I.E.E.

At the close of the Thirtieth Session the retiring Council presents the following Report upon the state of the Society.

THE ROLL OF THE SOCIETY.

The additions to the Roll of the Society at the close of the Annual Meeting on the 27th April, 1904, have been 39 compared with 43 in the previous Session, comprising 29 Members, 3 Associate Members, 3 Associates and 4 Students.

On the other hand, it has to be recorded that 19 names have been removed from the list as against 11 last year, all due to resignation. One transfer from the Associate Class to Membership took place during the Session. At the present date the number of Members of all classes is 535; being 9 Honorary Members, 10 Life Members, 1 Life Associate, 424 Ordinary Members, 11 Associate Members, 58 Associates and 22 Students.

THE SESSION AND MEETINGS.

The present Session was opened on the 4th November, 1903, by the President, Mr. Thomas L. Miller, M. Inst. C.E., M.I. Mech. E., M.I.E.E., who delivered his Inaugural Address before a full audience of Members and their friends.

After pointing out the vital importance of a cheap supply of power to the industrial welfare of the Country, the President proceeded to consider

the sources of energy upon which we may draw for mechanical power, and dealt with Tidal and Wave Energy, Wind, Water and Fuel.

Dealing, firstly, with tidal energy, he pointed out how the intermittent nature of the tidal current, the comparatively small range of the rise and fall available, and the very large extent of storage area required, all combined to restrict the attempt to utilise tidal energy to a few favoured localities, where, through the natural configuration of the ground, the necessary reservoirs could be constructed at small capital cost, and where the rise and fall of the tides were sufficiently great to permit of an adequate return on the capital expended on the necessary works.

Regarding wave energy he referred to the difficulties to be encountered as being almost insuperable, as although the energy of the waves was very great, it is most irregular in amount and requires very large apparatus for its utilisation.

As a cheap source of power, wind, he stated, held a very high position, but its extreme irregularity and the very large sail area required for but moderate powers, and the fact that the speed and rotation depends upon the velocity of the wind, militates greatly upon its use as a source of power for industrial purposes.

As regards water power, he considered that under favourable conditions it stood unrivalled as a cheap source of energy for industrial purposes. As a rule, however, it lies away from all manufacturing centres from which industries are slow to move.

In water power stations, he showed that the cost of power is made up principally of the charges for interest and for writing off the capital outlay, in addition to, in some instances, a royalty for the use of the water rights, which varies according to the circumstances, being, in most instances, just sufficient to bring the cost of water power below its established rival in the district. He then gave a large number of figures regarding the extent to which water power was used in the United States and on the Continent, the capital cost of a number of important water power plants, and the price at which electrical energy from water power stations is sold to consumers in the districts served by such stations.

In dealing with Fuel, the President reviewed the progress that had been made in the direction of the economical production of power from fuel, and gave a considerable amount of data showing the economical results that had been obtained at different times from coal and other fuel.

The utilisation of steam in the steam engine was then considered, and figures given, showing the improvement in the duty of the steam engine from the days of Watt up to the present time.

Steam Turbines were then dealt with, and the De Laval, Parsons and

Curtis' turbines described, and data given of published tests illustrating what might be expected from steam turbines under varying circumstances and working.

The vast possibilities possessed by the modern internal combustion engine were then considered, and descriptions given of the advances made in recent years, both in the production of gas, the utilisation of blast furnace gases, and the use of large power gas engines.

The cost of the production of power from fuel was next considered, and a considerable amount of data quoted on this point, after which the President concluded his address by pointing out the possibilities in the way of utilising the heat going to waste in many of our manufacturing processes, and as a striking illustration of this, he instanced the case of the utilisation of the waste gases from blast furnaces where, taking figures given by the late Mr. Bryan Donkin for the world's output of iron from blast furnaces in 1899, it would appear that the total indicated horse power from this source alone would be 6,400,000.

This was succeeded at subsequent meetings by papers and discussions upon the various Engineering subjects enumerated in the following summary :—

1903.

18th November.—Mr. J. B. C. Kershaw, F.I.C., F.S.S.—
"Fuel Economy from the Chemical Point of View."

2nd December—Mr. E. J. Hidden.—
"Recent Telephone Developments in Liverpool."

16th December.—Mr. H. W. Wilson, A.M.I.E.E.—
"Polyphase Machinery and Working."

1904.

13th January.—Mr. W. Norris, Assoc. M. Inst. C.E., M.I. Mech. E.—
"Motor Vehicles."

20th January.—Mr. H. S. Meyer.—
"Voltage Regulation in Alternating Current Systems."

27th January—Professor E. W. Marchant, D. Sc., A.M.I.E.E.—
"Induction Motors."

10th February.—Mr. E. Kilburn Scott, Assoc. M. Inst. C.E., M.I.E.E.—
"Long Distance Transmission from High Head Water Powers."

24th February.—Mr. George Balfour, M.I.E.E., A.M.I. Mech. E.—
"Conduit and Surface Contact Tramway Systems."

9th March.—Mr. J. Reney Smith, M.I. Mech. E., M.I.N.A.—
"Modern Marine Boiler Failures."

23rd March.—Mr. Louis J. Hunt, Assoc. M. Inst. C.E., A.M.I.E.E.—
"Notes on Design of Electrical Machinery."

6th April—Mr. A. H. Crump, M.I.M.E.—
"Some Experiments with Variable Pitch Propeller Blades."

27th April.—Annual General Meeting.

Election of Council and Officers.

Report of Council for the 30th Session.

Honorary Treasurer's Annual Statement of Receipts and Expenditure to the 31st December, 1903.

Presentation by the President of the Diploma Certificates to those Members, Associate Members, Associates and Students who had been elected to the Society during the past Session.

Appointment of Auditor for Session 1904-1905 (in accordance with Rule VI.).

The Council have pleasure in recording the very interesting visit paid by the President and Members of the Manchester Section of the Institution of Electrical Engineers on the evening of the 23rd March, ulto., when Mr. Louis J. Hunt's paper was read, and they trust that this may be the forerunner of other similar joint meetings, either in Liverpool, Manchester, or elsewhere.

DISCUSSIONS ON PAPERS.

The Council take this opportunity of expressing their gratification at the manner in which the members generally took part in the discussions on the various papers read during the Session, and hope that the same spirit will animate the Society in the future.

DERBY GOLD MEDAL.

The Derby Gold Medal for the 1902-1903 Session was awarded by the Council to Mr. Geo. C. Kenyon, Assoc. M. Am. Soc. C.E., *Member*, for his paper entitled:—"Temporary Dams," read before the Society on the 25th February, 1903.

SOCIETY'S PREMIUM.

The Society's Premium for the same Session was awarded by the Council to Mr. F. J. Haswell, M.I. Mech. E., *Member*, for his paper entitled:—"Notes on Hydraulic Machinery and the Distribution of Hydraulic Power," read before the Society on the 11th February, 1903.

Both of these presentations were made by the President on the 13th January, 1904.

CONDITIONS AS TO AWARD OF THE DERBY GOLD MEDAL AND SOCIETY'S PREMIUM.

As a matter of interest to members of the Society, the Council have thought it desirable to bring under their notice the conditions as to the award of the Derby Gold Medal and the Society's premium respectively. They are as follows:—

DERBY GOLD MEDAL.

The following are the terms and conditions agreed to in connection with the award of this medal:—

1.—The Medal to be called the DERBY GOLD MEDAL.

2.—The Medal to be awarded annually to the author of any paper read during the Session which a Special Committee, appointed by the Council, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council), and the Honorary Officers of the Society, may select as most worthy of such distinction.

3.—The Members of the Committee at a meeting called for the purpose, shall express their selection by vote, and in case of equality of votes the Chairman shall have a casting vote.

4.—No Member of the Committee having himself read a paper during the Session shall take part in the adjudication.

SOCIETY'S PREMIUM.

1.—That the Special Committee, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council) and the Honorary Officers of the Society appointed to award the DERBY GOLD MEDAL be requested to make a recommendation annually to the Council as to the award of the Society's premium to the author or authors of any paper or papers read during the previous Session which the Committee may consider worthy of such recognition.

2.—No paper, the author of which is a Member of the Council or for which the DERBY GOLD MEDAL is awarded shall be eligible for the Society's premium.

3.—The premium shall, subject to the approval of the Council in each case, be presented in the form of books or other articles which may be selected by the author of the paper as useful to him in his profession.

4.—The value of the premium shall in any year be such sum as the Council may prescribe not exceeding the sum which shall have accrued from the investment of the Society's premium fund and to be available for the purpose.

EXCURSION.

By the courtesy and kindness of the Managing Director (Mr. Robt. H. Edmondson) of the Garswood Hall Collieries Company, the members were enabled to visit and inspect their Coal Mines and Works at Brynn. The thanks of the Council have been duly conveyed to the Company.

ANNUAL DINNER.

The Annual Dinner of the Society took place at the Adelphi Hotel, Liverpool, on the evening of Thursday, the 28th January, 1904.

About 180 Members and their friends supported the President on that occasion.

The Society's guests included amongst others: The Lord Mayor of Liverpool (Right Hon. R. A. Hampson); The President of the Institution of Civil Engineers (Sir Wm. H. White, K.C.B., LL.D., F.R.S.); The Chairman of the Liverpool Water Committee (Alderman W. J. Burgess, J.P.); The President of the Manchester Association of Students of Civil Engineers (Mr. James Cartwright); The Chairman of Lloyd's Committee, Liverpool (Mr. Joseph Chadwick); The Clerk of the Peace for Lancashire (Mr. Harcourt E. Clare); The Chairman of the Manchester Section of the Institution of Electrical Engineers (Mr. Ed. W. Cowan); The Vice-Chancellor of the University (Mr. A. W. W. Dale, M.A.); The Deputy Chairman of the Liverpool Committee, Lloyd's Register (Mr. J. Davies); Local Representative of the Shipping Gazette (Mr. A. Douglass); The Chairman of the Marine Engineers and Naval Architects' Committee (Mr. Chris. Geddes); The Chairman of the Shipbuilders' Association (Mr. H. M. Grayson); The Senior Engineer and Surveyor of the Board of Trade (Mr. W. Harris); The President of the Incorporated Law Society (Mr. F. Marton Hull, B.A.); The Secretary of the Liverpool University Student Engineering Society (Mr. K. Mackenzie); Rev. Monsignor J. Nugent; The Chairman of the Timber Trades' Association (Mr. C. E. Paynter); The President of the Liverpool Provision Trade Association (Mr. R. L. Sandie); The President of the Manchester Association of Engineers (Mr. Alfred Saxon); The President of the Liverpool Corn Trade Association (Mr. J. Shepherd); The Chairman of the Liverpool Underwriters' Association (Mr. Harold Sumner); The Secretary of the Institution of Civil Engineers (Dr. J. H. T. Tudsbery); The President of the Institution of Mechanical Engineers (Mr. J. Hartley Wicksteed).

ATTENDANCE AT MEETINGS.

The Council have been very pleased to observe that the attendances at the Ordinary Meetings have been so satisfactory during the Session.

OBITUARY.

The Council regrets to announce the death of 2 members of the Society, viz., Mr. David Meldrum, late Manager of the Cheshire Lines Committee, and Mr. H. P. Maffiola, of Waterloo.

RECEIPTS AND EXPENDITURE.

In accordance with Rule VI, the Honorary Treasurer's Financial Statement of Accounts for the Year ended 31st December, 1903, has been duly audited by Mr. F. W. Marsh, C.A., and is presented herewith. (See page xiii.)

GROWTH OF THE SOCIETY.

The following Table shows the progress made by the Society since its commencement in 1875:—

Year	Honorary Members	Ordinary Members	Associate Members	Associates	Students	Total	New Members Elected	Deaths, Resignations, Transfers, &c.	Nett Increase	President for each Session
1875-76	—	51	—	—	—	51	—	—	—	C. H. Graham Smith
1877	3	68	—	—	—	71	20	—	20	
1878	3	82	—	—	—	85	17	3	14	Robinson Souttar
1879	3	73	—	—	—	76	4	13	—	M. E. Yeatman
1880	3	88	—	—	—	91	23	8	15	Alexander Ross
1881	4	93	—	—	—	97	18	12	6	Alfred Holt
1882	5	88	—	—	11	104	10	3	7	Frank B. Salmon
1883	5	96	—	—	8	109	10	5	5	Henry Bramall
1884	5	99	—	—	6	110	16	15	1	R. Ratsey Bevis
1885	5	109	—	—	4	118	19	11	8	William E. Mills
1886	5	120	—	—	11	136	28	10	18	Coard S. Pain
1887	7	144	—	—	15	166	32	2	30	John J. Webster
1888	6	151	—	—	18	175	30	21	9	C. H. Darbishire
1889-90	6	169	—	1	16	192	33	16	17	Henry H. West
1890-91	6	181	—	3	9	199	20	13	7	F. Hudleston
1891-92	5	191	—	6	11	213	19	5	14	John T. Wood
1892-93	3	219	—	8	10	240	35	8	27	R. E. Johnston
1893-94	2	221	—	11	13	247	29	22	7	H. P. Boulnois
1894-95	4	238	—	11	21	274	41	14	27	H. S. Hele-Shaw
1895-96	6	278	—	18	20	322	61	13	48	A. J. Maginnis
1896-97	8	311	—	25	19	363	49	8	41	S. B. Cottrell
1897-98	10	325	—	28	20	383	26	6	20	George Farren
1898-99	10	338	—	33	21	402	45	26	19	John A. Brodie
1899-00	10	416	—	55	21	502	119	19	100	A. Bromley Holmes
1900-01	10	425	—	59	24	518	27	11	16	J. A. F. Aspinall
1901-02	10	396	—	59	18	483	38	73	—	Arthur Musker
1902-03	9	417	8	63	18	515	43	16	27	Ernest S. Wilcox
1903-04	9	434	11	59	22	535	40	20	20	Thomas L. Miller

THE LIBRARY.

The following publications have been received during the year:—

From the editors and proprietors—"British Architect"; "Cassier's Magazine"; "Engineer's Gazette"; "Fielden's Magazine"; "Indian

Engineering"; "Mechanical Engineer"; "Page's Magazine"; "Public Health Engineer"; "The Traveller"; "The Ironmonger."

And also — "Annual Report, Chief of Engineers," U.S. Army; "Annual Report, Chief of Bureau of Steam Engineering, U.S.A."; "Trans. Incorporated Gas Institute"; "The Sanitary Inspector"; "Annual Report of the Chief Engineer of the Liverpool Water Works"; Technology Quarterly (Boston, U.S.A.); "Annual Report of the Manager of the Liverpool Corporation Tramways."

The Society exchanges Transactions with—

1. American Association for the Advancement of Science
2. American Institution of Electrical Engineers
3. American Institution of Mining Engineers
4. American Society of Civil Engineers
5. American Society of Mechanical Engineers
6. Association of Engineering Societies
7. Western Society of Engineers
8. British Association for the Advancement of Science
9. British Association of Waterworks Engineers.
10. Canadian Society of Civil Engineers
11. Chesterfield and Midland Counties Institution of Engineers
12. Civil and Mechanical Engineers' Society
13. École d'application du Genie Maritime, Paris
14. Engineers' Club of Philadelphia
15. Engineering Society Western Pennsylvania
16. Franklin Institute
17. Incorporated Gas Institute
18. Institute of Marine Engineers
19. Institution of Civil Engineers
20. Institution of Electrical Engineers
21. Institution of Engineers and Shipbuilders in Scotland
22. Institution of Mechanical Engineers
23. Institution of Naval Architects
24. Iron and Steel Institute
25. Junior Inst. of Engineers
26. Liverpool Architectural Society
27. Liverpool Philomathic Society
28. Manchester Association of Engineers
29. Manchester Literary and Philosophical Society
30. Midland Institute of Mining, Civil and Mechanical Engineers
31. Mining Institute of Scotland
32. North-East Coast Institution of Engineers and Shipbuilders
33. North of England Institute of Mining and Mechanical Engineers
34. North Western Sanitary Inspectors' Association.
35. Philadelphia Commercial Museum
36. Royal Institution of Cornwall
37. Royal Philosophical Society of Glasgow
38. Royal Physical Society of Edinburgh
39. Smithsonian Institution
40. Society of Architects
41. Society of Arts of the Massachusetts Institute of Technology
42. Society of Engineers
43. South Wales Institute of Engineers
44. Stevens Institute of Technology
45. University of California
46. Yorkshire College Engineering Society

The Transactions of the Society are presented to—

47. "American Engineer and Railroad Journal"
48. Bootle Free Public Library
49. "British Architect"
50. Chief of Engineers U.S. Army
51. "Engineer"
52. "Engineering"
53. Engineering Department, Liverpool University
54. "Fielden's Magazine"
55. "Indian Engineering"
56. Liverpool Free Public Library
57. "Mechanical Engineer"
58. McGill University, Montreal
59. Patent Office Library
60. Society of Arts
61. University of Minnesota

Total Number of Transactions exchanged with, and presented to, other Societies = 61.

LIVERPOOL ENGINEERING SOCIETY

Dr. STATEMENT of RECEIPTS and EXPENDITURE to the 31st DECEMBER, 1903. Cr.

RECEIPTS.

				£	s.	d.
To Balance from last Account, viz.:—						
Lloyds Bank		£113	1	9		
Assistant Treasurer		3	3	0		
				116	4	9
" Subscriptions due 1st January, 1903—						
249 Resident Members		261	9	0		
167 Non-Resident Members		87	13	6		
45 Resident Associates		47	5	0		
18 Non-Resident Associates		9	9	0		
19 Students		9	19	6		
499		415	16	0		
Add Arrears from 1902		61	8	6		
		477	4	6		
Deduct Amount received in advance in 1902..	£7 7 0					
" Arrears written off during year	44 2 0					
" " to 1904	67 5 0					
		118	14	0		
		358	10	6		
Add Amount received for 1904		7	7	0		
				365	17	6
" Dividend on £150 L. & Y. Railway 3% debenture stock				4	4	9
" " £250 Midland Railway 2½% Pref. stock				8	16	5
" Bank Interest, 3/15/7; less Commission, 12/2				3	3	5
" Lord Derby for Gold Medal		10	0	0		
" Oldfields, Ltd.—Cost of Medal		9	9	0		
				0	11	0
Total				£498	17	10

EXPENDITURE.

				£	s.	d.
By Royal Institution Rent to February 14th, 1904				20	0	0
" " " Attendant to 14th Sept., 1903				3	3	0
" Postages and Sundries				4	16	11
" Stationery, Postages, Notices, Transactions, Official Books, &c.				35	0	0
" General Printing—Notices of Meetings, Dinner, Excursions, Annual Reports, &c.				43	4	6
" Printing, Illustrating, and Binding Transactions (Volume XXIV), (including Postages, &c.)				104	0	2
" Annual Dinner, 1903—						
Hotel Account, &c.	£194	16	1			
Less Proceeds of Tickets Sold	149	2	0			
				45	14	1
" Assistant Secretaries to 7th November, 1903				50	0	0
" " Treasurer to 29th April, 1903				10	0	0
" Audit Fee to 31st December, 1902				5	5	0
" Cost of Lantern Exhibitions				2	0	0
" Balance in Lloyds Bank, Ltd.	£174	13	2			
" " in hands of Assistant Treasurer	1	1	0			
				175	14	2
Investment Account—						
£150 Lanc. & York. Rly. 3% deb. stock cost	£169	12	0			
£250 Midland Rly. 2½% pref. stock cost	202	12	2			
	£372	4	2			
Total				£498	17	10

I have examined this Account with the Books and Accounts of the Society, and certify the same to be corrrect.

I have ascertained that the Certificate of the Debenture and Preference Stock as mentioned above are deposited with Lloyds Bank, Limited, Liverpool, and I have further verified the Balance at the Bankers.

Liverpool, 10*th March*, 1904.

(Signed) FRED. W. MARSH, Chartered Accountant.

LIVERPOOL ENGINEERING SOCIETY.

Dr. PERMANENT PREMIUM FUND, as at 31st DECEMBER, 1903. Cr.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance from last Account...	1	13	6	By 4th Premium—Mr. P. M. Pritchard (Session 1901-1902)... ...	5	5	0
" Interest on £105 North Eastern Railway Consols, less Tax	5	11	3	" Balance in Lloyds Bank	1	19	9
	£7	4	9		£7	4	9

I have examined the above Account with the Books and Vouchers of the Society, and certify the same to be correct.

I have ascertained that the Certificates of the £105 North Eastern Railway Consols are deposited with Lloyds Bank, Limited, Liverpool, and I have further verified the Balance at the Bankers.

LIVERPOOL, 10*th March*, 1904.

(Signed) FRED. W. MARSH, *Chartered Accountant.*

LIVERPOOL ENGINEERING SOCIETY.

ESTABLISHED 10th NOVEMBER, 1875.

Rules and Regulations.

OBJECT OF THE SOCIETY.

The promotion of the study and practice of Engineering.

RULE I.

Constitution.

The Society shall consist of Honorary Members, Members, Associate Members, Associates, and Students.

"Honorary Members" shall be men of eminent scientific attainments, elected from time to time by the Society.

"Members" shall be persons of not less than 25 years of age, who shall have been regularly educated as Engineers according to the usual routine of pupilage or apprenticeship, and who shall be actually engaged at the time of application for election in a responsible position in any branch of the profession of Engineering, or who shall, in the opinion of the Council, have attained such experience in any branch of the profession as to qualify them for Membership.

"Associate Members" shall be persons of not less than 21 years of age, who shall have been regularly educated as Engineers, and who shall, at the time of application for election, be engaged in connection with the design, construction or superintendence of some engineering work or undertaking.

Honorary Members, Members, and Associate Members, shall be entitled to all the privileges of membership of the Society, and shall be deemed to be included, where not inconsistent with the context, in the expression "member" hereafter appearing.

Associates shall be persons of not less than 21 years of age, who are not Engineers by profession, but who, by their connection with science or the arts, or otherwise, are qualified to co-operate with Engineers in the advancement of professional knowledge.

Students shall be persons under 21 years of age, in course of training to become Engineers.

"Associates" and "Students" shall have all the privileges of membership, except that they shall not be eligible for election to the Council otherwise than as Officers, and shall not have a right to take any part in the proposal or election of candidates for the Society, or to vote.

RULE II.

Election of Candidates.

Every candidate for election as a member or associate shall be proposed and recommended according to Form A in the Appendix.

Every candidate for election as a student shall be proposed and recommended according to Form B in the Appendix.

These forms being duly filled in, must be signed by at least three members certifying personal knowledge of the candidate and testifying to his qualification. In the case of the proposal of an Honorary Member the form shall be signed by a majority of the members of Council.

The Council shall examine each proposal form and shall decide whether the qualifications of the person proposed satisfy the necessary conditions for admission to the Society, and if so, in which class he is qualified to be admitted. The Honorary Secretary shall submit the proposal form to the next following Ordinary Meeting of the Society, and shall report that the proposal form has been examined and approved by the Council.

The proposal form shall be open for inspection at the meeting, and for a period of 12 days thereafter, and the candidate shall thereupon become eligible for election at the next following Ordinary Meeting of the Society.

The Honorary Secretary shall cause the names and addresses of all candidates eligible for election to the Society, with the names of their proposers and seconders, to appear on the notice convening the next Ordinary Meeting of the Society.

The election shall be by ballot, and every candidate shall be declared to be elected unless there be at least one negative vote for every three affirmative votes.

The proposal for transferring any person from the class of Associate Member to the class of Member shall be according to Form C in the Appendix. Such form shall be signed by at least six members and delivered to the Honorary Secretary, and shall be submitted to the Council, who may, if they consider the qualifications of the candidate justify such course, make the proposed transfer.

RULE III.

Residence.

Members, Associate Members, or Associates residing or being engaged in a place of business within ten miles of the Liverpool Exchange shall be considered Resident Members, Associate Members, or Associates respectively, those beyond such limits Non-resident Members, Associate Members, or Associates respectively.

Subscriptions.

The Subscription shall be, for each Resident Member, Associate Member, or Associate, One Guinea per annum; for each Non-resident Member, Associate Member, or Associate, and for each Student, Half-a-Guinea per annum.

Subscriptions shall be due and become payable on each first of January for the year ensuing, or, in the case of persons newly elected, within one month of their election, except in the case of those elected in any year during the month of November, in which case their subscriptions shall not be due until the 1st of January following.

Any Member, Associate Member, or Associate, may compound for the Annual Subscription by the payment of Ten Guineas, and so become a Life Member, Associate Member, or Associate.

Any Member, Associate Member, Associate, or Student not having paid his Subscription within three calendar months after a second notification by the Secretary that it is due, shall be reported to the Council, who may order his name to be removed from the Register of the Society.

RULE IV.

Council and Officers.

Past Presidents.

Officers.

The Council of the Society shall consist of a President, two Vice-Presidents, and twelve other members, and they, together with the following *ex-officio* members of Council, shall manage the affairs of the Society. Four shall form a quorum. Past Presidents shall be *ex-officio* members of the Council for five consecutive years after their retirement from office. The officers of the Society shall be an Honorary Solicitor, Honorary Librarian, Honorary Treasurer and Honorary Secretary, who shall be elected from amongst the Members, Associates and Students of the Society, and they shall be *ex-officio* members of the Council.

The President shall preside at all meetings of the Society and of the Council at which he is present, and shall regulate and keep order in the proceedings. President.

In the absence of the President, it shall be the duty of one of the Vice-Presidents to preside. Vice-Presidents

In the absence of the President and Vice-Presidents, the members present shall elect a Chairman to preside at the meeting.

The Honorary Solicitor shall, from time to time, give his advice to the President and members of the Council upon any legal matters arising out of the business of the Society. Honorary Solicitor.

The Honorary Librarian shall receive and be responsible for the whole of the books, papers, drawings, models, &c., belonging to the Society. He shall keep a catalogue of all such books, papers, &c., and shall lend them to the members, under regulations to be sanctioned by the Council. Honorary Librarian.

The Honorary Treasurer shall collect all sums due to the Society, and pay the same into one of the Liverpool Banks to the credit of the Society. He shall pay all sums due by the Society, by cheque, signed by two members of the Council, and keep an account of the income and expenditure in a Cash Book provided for the purpose; such Cash Book shall be open for inspection by the Council at any Council Meeting. He shall produce, at the last Council Meeting in March of each year a printed Statement of the Receipts and Expenditure for the previous year, and a Statement of Liabilities and Assets. Honorary Treasurer.

The Honorary Secretary shall act under the direction of the Council, and shall conduct the correspondence of the Society, take minutes of the Proceedings at all meetings, and enter them in the Minute Books, read the Minutes and Notices at all meetings, revise and edit the Transactions, and keep a Register of the members of the Society. Honorary Secretary.

The Honorary Officers of the Society shall be ex-officio entitled to all the privileges of membership of the Society.

RULE V.

At an Ordinary Meeting, at least two weeks before the Annual General Meeting, the Council shall present a list of persons, being members, whom they nominate as suitable for the offices of President, Vice-Presidents, members of the Council and Honorary Officers for the ensuing year, and at the same meeting the name of any member shall be added to the list on the nomination of two members present at the Meeting. Election of Council and Officers.

Such list shall include the names of not less than 12 members of the Council, exclusive of the President, 2 Vice-Presidents, and Honorary Officers.

At the Ordinary Meeting next before the Annual General Meeting, the members shall choose two or more persons as scrutineers for the purposes of the ballot. The balloting list shall immediately after the Ordinary Meeting at which it has been presented by the Council, be issued to all members in the United Kingdom, and shall be returned to the Honorary Secretary, at least three days before the Annual General Meeting, in a closed envelope, and marked "Balloting List."

The scrutineers shall open the envelopes and count the votes and report the result at the Annual General Meeting. Any balloting list on which a member has voted for a number, either more or less than one President, two Vice-Presidents, 12 members of Council, and the Honorary Officers, shall be rejected by the scrutineers.

The newly-elected Council and Officers shall take office on the first Wednesday in November, up to which date the old Council and Officers shall continue in office.

Any vacancy occurring in the Council or among the Honorary Officers during the year shall be filled up by the Council.

RULE VI.

Auditors.

The Treasurer's Annual Statement of the receipts and expenditure for the previous year and his statement of liabilities and assets shall, after being duly audited by an auditor to be appointed at the preceding Annual General Meeting, be presented to the members together with the Report at the Annual General Meeting.

RULE VII.

Session and Meetings.

The Session of the Society shall commence annually on the first Wednesday in November, and terminate on the last Wednesday in April.

The Ordinary Meetings of the Society shall be held on alternate Wednesdays at Eight p.m., from November to April, inclusive, or oftener at the discretion of the Council. The Meetings shall be limited to an hour and a half's duration, but in the event of the proceedings not being completed in the hour and a half, the time may be extended, or the discussion adjourned by a vote of the Meeting.

The order of procedure at each Ordinary Meeting shall be:—

1.—The Minutes of the previous Meeting, after having been read and confirmed, shall be signed by the Chairman.

2.—Business arising out of the Minutes.

3.—Communications from the Council.

4.—Candidates for election to be announced.

5.—Candidates for election to be balloted for.

6.—Any member present for the first time since his election, having paid his subscription, and signed the Register, to be introduced by the Chairman to the Meeting.

7.—Original communications to be read and discussed.

8.—General Business.

The Annual General Meeting of the Society shall be held on the last Wednesday in April, to receive the Treasurer's Statement and the Annual Report, to appoint an auditor for the ensuing year and fix his remuneration, and to receive the Scrutineers' Report as to election of Officers and Council for the ensuing year.

RULE VIII.

Special Meetings

The Council may at any time call a Special Meeting of the Society, and shall at all times be bound to do so on the receipt of a requisition signed by not less than ten members, stating the purpose for which the Meeting is to be convened. In either case, at least seven days' notice of the time appointed by the Council for such Meeting shall be given to every member and the Meeting shall be held within twenty-one days after the receipt of the requisition. The notice shall specify the nature of the business to be transacted, and no other business shall be transacted at that Meeting.

RULE IX.

All votes on any question brought before the Society shall be given in person; except votes for the election of the Council and Honorary Officers, which shall be in accordance with Rule V. Voting.

In the event of equality of votes, the Chairman shall have a second or casting vote.

RULE X.

The Manuscript of the Papers read, or legible copies thereof, shall become the property of the Society, and shall not be published without the permission of the Council. Manuscript of Papers.

RULE XI.

Any member, associate, or student not complying with the Rules of the Society, or guilty of misconduct, may be requested by the Council to send in his resignation to the Secretary. But if he fail to do so, the Council may bring his case before a Special Meeting, who shall be entitled to expel him from the Society, or deal with the matter as they may deem expedient. Expulsion from the Society.

RULE XII.

Visitors may be admitted to an Ordinary Meeting, on the introduction of a member, associate or student, who shall enter their names in the attendance book. Visitors.

RULE XIII.

No addition to or change in these Rules shall be made except by a vote of not less than two-thirds of the members present at a Special Meeting to be convened for that purpose. Addition to, or Alteration in Rules.

APPENDIX.

[FORM A.]

Mr. ..... of .....

being of not less than twenty-$\frac{\text{one}}{\text{five}}$ years of age, born on the ..... day of .....,

and being desirous of becoming a ..... of the LIVERPOOL ENGINEERING SOCIETY, I recommend him, from personal knowledge, as in every respect worthy of election.

The candidate .....

Here specify fully such facts, with dates, *concerning the education and career of the candidate as he, or his proposer, may deem necessary to convince the members that the candidate has the proper qualifications for membership:—*

(*vide* Rule I.)

.....

On the above grounds I propose him to the Council as a proper person to belong to the Society.

(Signed) ..... *member.*

Date .....

We, the undersigned, concur in the above recommendation from personal knowledge and second the proposal.

.....	.....	members
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

In the event of my being elected a of this Society I hereby agree to observe and conform to all the Rules and Regulations thereof and to pay all Subscriptions and other sums which under the said Rules and Regulations shall from time to time become due from me to the Society or to any Officer thereof.

Signature of candidate.....

The Council having considered the above recommendation present.....to be balloted for as a.....of the LIVERPOOL ENGINEERING SOCIETY.

(Signed).....*Chairman.*

(Date).....

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III.]

Examined by the Council ..... *Read at the Ordinary Meeting*.....*Balloted for*.....

APPENDIX.

[FORM B.]

Mr. ..... of .....

born on the ..... day of ....., being desirous of admission as a Student

of the Society, I recommend him, from personal knowledge, as in every respect worthy of election.

The candidate.....

Here specify fully such facts, with dates, *concerning the education of the candidate as he, or his proposer, may deem necessary to convince the members that the candidate has the proper qualifications for studentship:—*

(*vide* Rule I.)

.....

.....

.....

.....

.....

.....

On the above grounds I propose him to the Council as a proper person to become a Student of the Society.

(Signed)..... *member.*

Date.....

We, the undersigned, concur in the above recommendation from personal knowledge, and second the proposal.

.....	.....	*members*
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

In the event of my being elected a Student of this Society I hereby agree to observe all the Rules and Regulations thereof, and to pay all Subscriptions and other sums which under the said Rules and Regulations shall from time to time become due from me to the Society or to any Officer thereof.

Signature of candidate .....

The Council having considered the above recommendation present .....to be balloted for as a Student of the LIVERPOOL ENGINEERING SOCIETY.

(Signed) .....*Chairman.*

(Date) .....

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III.]

Examined by the Council .....*Read at the Ordinary Meeting* .....*Balloted for* .....

APPENDIX.

[FORM C.]

We, whose names are hereunto subscribed, submit to the Council of the LIVERPOOL ENGINEERING SOCIETY the propriety of transferring Mr. ..... of .....

born on the ..... day of ..... , to the class of Members, because

Here specify distinctly the qualifications of the candidate, according to the spirit of Rule II.

.....

.....

.....

.....

.....

.....

Witness our hands this ..... day of .....

.....	.....	members.
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

The Council of the LIVERPOOL ENGINEERING SOCIETY, meeting on the ..... day of ....., transfer Mr. ..... from the class of Associate Members to the class of Members.

(Signed) ..... *Chairman.*

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III].

Examined by the Council ..... *Read at the Ordinary Meeting* ..... *Balloted for* .....

LIVERPOOL ENGINEERING SOCIETY.

HONORARY MEMBERS.

DATE OF ELECTION	NAME	ADDRESS
24th Apl., 1895	Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S., M.Inst.C.E.	2, Queen Square Place, Westminster
31st Mar., 1897	Barry, Sir John Wolfe, K.C.B., F.R.S., M. Inst. C.E.	23, Delahay Street, Westminster, London, S.W.
8th Jan., 1896	Derby, Right Hon. The Earl of, K.G., G.C.B.	Knowsley, near Liverpool
31st Mar., 1897	Fox, Sir Douglas, M. Inst. C.E.	28, Victoria Street, Westminster, London, S.W.
24th Apl., 1895	Kelvin, Right Hon. Lord, LL.D., F.R.S.	The Library, The University, Glasgow
3. 8th Nov., 1882	Lodge, Sir Oliver Joseph, D. Sc., F.R.S.	University College, Birmingham
1. 8th Jan., 1896	Preece, Sir W. H., C.B., F.R.S.	Gothic Lodge, Wimbledon, Surrey
2nd Feb., 1881	Reynolds, Osborne, M.A., F.R.S.,	Owens' College, Manchester
2nd Mar., 1898	White, Sir William H., K.C.B., LL.D., F.R.S.	Cedarcroft, Putney Heath, London

9 Total Number of Honorary Members.

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

MEMBERS.

DATE OF ELECTION	NAME	ADDRESS
17th Feb., 1897	Adamson, John, Assoc. M. Inst. C.E.	152, Bedford Road, Bootle
2nd Mar., 1898	Aitchison, G. C., Assoc. M. Inst. C.E.	Snowdon Mountain Railway, Llanberis, North Wales
8th Nov., 1893	Alexander, John T.	Building Surveyor's Office, Municipal Buildings, Liverpool
19th Feb., 1896	Allen, Cecil A.	White Star Works, Bootle
19th Feb., 1896	**Allen, Edward,** M. I. Gas E. *Member of Council.*	Gas Office, Duke Street, Liverpool
4th Apl., 1900	Allen, S. Proctor	Royal Insurance Co., 1, North John Street, Liverpool
15th Nov., 1899	Allenby, R. P.	23, Prospect Vale, Fairfield, Liverpool
13th Dec., 1899	Allott, Charles S., M. Inst. C.E., M.I. Mech. E.,	46, Brown Street, Manchester
13th Dec., 1899	Allott, Henry N., Assoc. M. Inst. C.E.	46, Brown Street, Manchester
26th Nov., 1890	Aman, Frederick T., Assoc. M. Inst. C.E.	City Engineer's Office, Municipal Buildings, Liverpool
2. 7th Nov., 1894	Anderson, J. Wemyss, Assoc. M. Inst. C.E., M. I. Mech. E.	The University, Liverpool
13th Nov., 1895	**Armistead, Reginald W.** *Hon. Librarian.*	11, Derwent Drive, Liscard, Cheshire
21st Feb., 1900	Armstrong, F. C.	Messrs. Dick Kerr and Co., 110, Cannon Street, London, E.C.
4th Apl., 1900	Ashmore, Thomas	Westmoreland Foundry, Westmoreland Place, Liverpool
1. 13th Nov., 1895	**Aspinall, John A. F.,** M. Inst. C.E., M. I. Mech. E., M.I. and S. Inst. *Past President,* 1900-1901. (*Life Member.*)	Gledhill, Mossley Hill Drive, Liverpool
22nd Mar., 1899	Atkins, Evan A., A.M.I.Mech. E.,	9, Breckside Park, Anfield, Liverpool
4th Apl., 1900	Bach, John E., Assoc. M. Inst. C.E.	
26th Nov., 1890	Baird, Andrew H.	22, Dutton Street, Liverpool
28th Jan., 1903	Baldry, H. O., M. Inst. C. E.	21, Queen Anne's Gate, Westminster, London, S.W.
11th Jan., 1893	Barclay, George	c/o Messrs. J. Glynn & Son, 14, Chapel Street, Liverpool
1. 13th Nov., 1895	Barham, H. G. Foster, Assoc. M. Inst. C.E.	Water Engineer, Brisbane, Queensland
20th Dec., 1893	Barker, Eric G., M. I. Mech. E.,	5, Rice Hey Road, Egremont
1. 18th Nov., 1903	Balfour, George	c/o Messrs. J. G. White & Co., 22a, College Hill, Cannon Street, London, E.C.

	DATE OF ELECTION	NAME	ADDRESS
	7th Nov., 1894	Barnes, J. E. Lloyd, Wh. Sc., M.I. Mech. E.	34, Castle Street, Liverpool
	2nd Nov., 1887	Barton, A., Assoc. M. Inst. C.E., A.M.I. Mech. E.	21, Northumberland Avenue, Charing Cross, London, W.C.
	19th Nov., 1902	Bates, William, Assoc. M. Inst. C.E.	Deva Cottage, Rose Mount, Oxton
	30th Jan. 1901	Barty, A. Douglas, A.M.I. Mech. E.	17, St. Edmonds Road, Bootle
	31st Jan., 1894	Bayley, George R.	21, Victoria Road, Waterloo, near Liverpool
	7th Nov., 1894	Beckett, William M., Assoc. M. Inst. C.E.	Temple Chambers, 33, Brazennose Street, Manchester
	29th Nov., 1899	Bell, Allan, A.M.I. Mech. E.	34, Kimberley Street, Liverpool, S.
1.	5th Nov., 1884	Bellamy, C. R., Assoc. M. Inst. C.E.	Corporation Tramways Department, 6, Sir Thomas Street, Liverpool
2.	13th Mar., 1878	**Bevis, R. Ratsey,** M. Inst. C.E., *Past President*—1884.	Birkenhead Iron Works, Birkenhead
1.	21st Nov., 1894	Bigley, Thomas M., Assoc. M. Inst. C.E.	19, Castle Street, Liverpool
	4th Dec., 1901	Bingham, James B.	Electricity Works, Victoria Road, Kirkaldy
	5th Dec., 1900	Bishop, C. Herbert, Assoc. M. Inst. C. E., A.M.I. Mech. E.	89, Hanover Street, Liverpool
	23rd Jan., 1889	Blackburn, R. N., Wh. Sc.	Messrs. Blackburn & Sons, 20, North John Street, Liverpool
1.	11th Dec., 1895	Blair, Malcolm	Messrs. Francis Morton & Co., Garston, Liverpool
1.	19th Oct., 1887	Blair, W. N., M. Inst. C.E.,	Vestry Hall, St. Pancras Road, London, N.W.
	4th Apl., 1900	Blakeley, E. F.	10, Somerville, Poulton Road, Seacombe
	25th Feb., 1885	Blood, F. W.	Grafton Saw Mills, Grafton Street, Liverpool
	28th Jan., 1903	Blundell, Harry, M. Inst. C.E.	44, Grosvenor Road, Claughton, Birkenhead
	4th May, 1892	Boscawen, P. Noel, Assoc. M. Inst. C.E.	Dock Yard, Liverpool
1.	26th Mar., 1890	**Boulnois, H. Percy,** M. Inst. C.E., F.S.I., *Past President*—1893-94.	Abbey Cottage, Bisham, Marlow
5.	24th May, 1876	Boult, W. S., Assoc. M. Inst. C.E.,	32, North Side, Wandsworth Common, London, S.W.
	16th Nov., 1898	Bourne, J.	Surveyor, Urban District Council, Rawmarsh, Yorks.
	8th Dec., 1875	Bovey, Henry T., M.A. Cantab., Assoc. M. Inst. C.E.	Professor of Engineering, McGill University, Montreal, Canada
	9th Nov., 1892	Bowden, F. W., Assoc. M. Inst. C.E.,	18, Eastern Drive, Grassendale, Aigburth.
	23rd Jan., 1889	Bower, W. Nelson, M. I. Mech. E., Assoc. M. Inst. C.E.	402, Lytham Road, South Shore, Blackpool
	7th Mar., 1900	Boyd, Chas. A.	
1.	27th Sept., 1880	**Bramall, Henry,** M. Inst. C.E. *Past President*—1883.	Pendlebury Collieries, near Manchester
	25th Jan., 1888	**Brew, J. B.** *Member of Council*	32, Deane Road, Liverpool
	13th Feb., 1878	Brinckman, William, Assoc. M. Inst. C.E.	Dinorwic Quarries, Llanberis, Carnarvon

DATE OF ELECTION	NAME	ADDRESS
2. 22nd Oct., 1884	**Brodie, John Alexander,** Wh. Sc., M. Inst. C.E., M. I. Mech. E. *Past President*—1898-99.	City Engineer, Municipal Buildings, Liverpool
29th Jan., 1902	**Brodie, Robert,** M. Inst. C.E. *Member of Council.*	17, Priory Street, Birkenhead
.W. 9th Nov., 1892	**Brodie, William,** Assoc. M. Inst. C.E. *Member of Council*	Engineer's Office, Dock Yard, Liverpool
.S. 7th Nov., 1894	Brown, David	Canal Ironworks, Hawthorne Rd., Bootle
14th Jan., 1903	Browne, W. D. Shaw	40, Plattsville Road, Allerton Road, Liverpool
3rd Apl., 1895	Browne, Wallis V.	36, Orrell Park, Aintree, L'pool
11th Dec., 1895	Brownridge, Charles, Assoc. M. Inst. C.E.	Borough Surveyor, Town Hall, Birkenhead
18th Mar., 1896	**Bruce, W. J. Willett,** R.N.R. *Member of Council*	White Star Works, Strand Road, Bootle
28th Jan., 1903	Bruce, Wm. T. C.	49, Sefton Street, Liverpool
25th Jan., 1888	Buchanan, J. H., Assoc. M. Inst. C.E., M.I.N.A.	Oswald Chambers, 5, Oswald Street, Glasgow
22nd Jan., 1896	Buckwell, G. W., Wh. Sc., M. I. Mech. E., M.I.N.A., M. I. Mar. E.	Board of Trade Surveyor's Office, Barrow-in-Furness
21st Nov. 1900	Bullough, C. Oswald	
2nd Mar., 1898	Bunch, Charles E.	Dallam and Bewsey Forges, Warrington
15th Nov., 1899	Burlton, F. J.	Messrs. J. Crosfield & Sons, Warrington
3. 14th Feb., 1883	Burton, G. L., Assoc. M.Inst. C.E.,	Ymuiden, Warren Road, Blundellsands
27th Jan., 1892	Bush, Robert, B.A., M. Inst. C.E.	Engineer's Office, Dock Yard, Liverpool
12th Nov., 1890	Bushell, Edward H., M.I.N.A.	43, Castle Street, Liverpool
4th Apl., 1900	Callender, Thomas O., M.I.E.E.,	Hamilton House, Victoria Embankment, London, E.C.
18th Nov., 1803	Callow, Douglas J.	17a South Castle Street. Liverpool
18th Mar., 1896	Calthrop, Everard Richard, M. Inst. C.E., M.I. Mech. E.	3, Crosby Square, Bishopgate Street Within, London, E.C.
15th Jan., 1890	Capstick, R.	74, Grafton Street, Liverpool
4th Apl., 1900	Carr, Isaac, M. Inst. C.E.	Farnworth, Widnes
8th Nov., 1893	Carruthers, J. W. B.	
14th Jan., 1903	Carter, Arthur H.	Public Offices, Litherland
15th Nov., 1899	Carter, Richard	Liverpool Gas Works, Garston
9th Mar., 1887	Carter, William	Hydraulic Eng. Co., Chester
26th Feb., 1890	Cartwright, Joshua, M. Inst. C.E.,	Peel Chambers, Bury, Lancs.
15th Nov., 1899	Catchpole, J. W.	163, Moscow Drive, Stoneycroft, L'pool
27th Nov., 1895	Caulton, Fred.	14, Hemans Street, Liverpool
16th Nov., 1898	Chandler, Lincoln	
13th Dec., 1899	Chapman, Alfred, M. Inst. C.E.	Messrs. Fawcett, Preston & Co., York Street, Liverpool
13th Nov., 1895	Clarke, G. Edgar, Assoc. M. Inst. C. E.	Borough Surveyor, Municipal Offices, Boston, Lincolnshire
16th Nov., 1899	Clarke, Herbert G., Assoc. M. Inst. C.E.	City Engineer's Department, Guildhall, Nottingham
11th Nov., 1896	Clarke, John H.	Monkbridge Iron and Steel Works, Leeds

	DATE OF ELECTION	NAME	ADDRESS
	20th Nov., 1901	Cliff, Thomas P. B.	The Admiralty, 21, Northumberland Avenue, London
	4th Dec., 1901	Clothier, T. Dawson	Electric Light and Power Station, Pine Grove, Bootle
	10th Jan., 1900	Clough, Alfred, Assoc. M. Inst. C.E.	74, Lark Lane, Liverpool
	19th Feb., 1896	Clover, Matthew, M.I.N.A.	Rose Brae, Birkenhead
	13th Nov., 1895	Collard, Alfred S.	Messrs. R. P. Houston & Co., Dale Street, Liverpool
	11th Nov., 1896	Collard, J. A., M.I.N.A.	61, Drury Buildings, 21, Water St.
1.	21st Nov., 1883	Collier, H. M. H., Assoc. M. Inst. C.E.	North Eastern Railway, Engineer's Office, New Dock Works, Middlesbrough
	21st Mar., 1900	Collins, Brierley H., M.I.E.E.	17, Hawarden Avenue, Sefton Park, Liverpool
1.	7th May, 1890	Collis, W. H., Assoc. M. Inst. C.E.,	7, Barn Hill Road, Wavertree
	12th Jan., 1887	Comerford, Edward, A. M.I. Mech. E.	Abbot's Grange, Liverpool Road, Chester
	6th Apl., 1887	Cook, E.	18, Esplanade, Waterloo
	15th Nov., 1899	Cooke, Rupert T.	44, Lidderdale Road, Sefton Park
1.	12th Jan., 1887	**Cooper, Francis E.,** Assoc. M. Inst. C.E. *Member of Council.*	City Engineer's Department, Municipal Buildings, Liverpool
1.	4th Apl., 1894	Corbett, Joseph, M.S.I.	Borough Engineer, Town Hall, Salford
2.	10th Oct., 1877	Cornish, E. S.	Bryngoleu, Holyhead
	26th Mar., 1902	Corrie, H. W.	Surveyor, Urban District Council Offices, Lower Bebington, Cheshire
	5th Dec. 1900	Cottle, Frank	Borough Surveyor's Office, Douglas, Isle of Man
1.	26th Feb., 1890	**Cottrell, S. B.,** M. Inst. C.E., M.I. Mech. E. *Past President*—1896-97.	L'pool Overhead Railway, Pacific Buildings, 31, James Street
	9th Apl., 1902	Coulston, Percy B.	c/o The Brush Electrical Engineering Co., Limited, Haworth's Building, Cross Street, Manchester
	12th Feb., 1902	Cowper, J. W.	
	21st Mar., 1900	Crawford, John P.	
	16th Dec., 1903	Crawford, R. S.	58, Kenmare Road, Sefton Park, Liverpool
	5th Feb., 1896	Crichton, Charles	Huskisson Engine Works, L'pool
	1st April, 1896	Crouch, John P., Assoc. M. Inst. C.E.	Locomotive Works, L. & Y. Ry., Horwich, Lancashire
1.	16th Nov,, 1898	Crump, Arthur H., M.I.M.E.	21, Dale Street, Liverpool
1.S.	20th Feb., 1895	Cunningham, Brysson, B.E., Assoc. M. Inst. C.E.	6, Neville Road, Waterloo
	17th Nov., 1897	Daglish, Harry B., M. I. Mech. E.,	Messrs. Robert Daglish & Co., St. Helens
5.	16th Mar., 1881	**Darbishire, Charles Henry,** J.P., Assoc. M. Inst. C.E. *Past President*—1888. *(Life Member.)*	Penmaenmawr, North Wales
	11th Jan., 1893	Darby, Jas. T.	Church Street West, Bootle
1. S.	17th Nov., 1897	Davidson, J. R., M. Sc., Assoc. M. Inst. C.E.	6, Ivanhoe Road, Sefton Park, Liverpool
	13th Nov., 1895	Davies, Charles Edward	
	9th Nov., 1892	Davies, Fred. Wm.	Water Engineer's Department, Municipal Offices, St. Peter's Churchside, Nottingham

DATE OF ELECTION	NAME	ADDRESS
20th Feb., 1889	Davies, T.	Canning Dock Works, Liverpool
11th Nov., 1896	Davies, T. W., Assoc. M. Inst. C.E., F.G.S.	41, Park Place, Cardiff
12th Apl., 1893	Davies, William	65, Parkgate Road, Chester
18th Dec., 1901	Davis, Frank	Superintendent Engineer, County Asylum, Littlemore, Oxford
20th Nov., 1901	Daw, Hilder, M.R.I., A.I.N.A.	Royal Societies' Club, St. James Street, London, S.W.
1. 25th Apl., 1877	Deacon, George F., LL.D., M. Inst. C.E., M. I. Mech. E.	Gt. George Street Chambers, 16, Gt. George St., Westminster, S.W.
1. 15th Nov., 1899	Deakin, G. Welsby, Assoc. M. Inst. C.E., A.M.I. Mech. E.	Resident Engineer, Sewerage & Water Works, Talgarth, Brecon
28th Mar., 1877	Dickson, John, Assoc. M. Inst. C.E.,	Glaisdale Ironworks, Grosmont, Yorks.
12th Nov., 1890	Douglas, James T.	Queen B'dgs, 11, Dale St., Liverpool
7th Feb., 1900	Downe, Reginald S.	Town Hall, Southport
13th Nov., 1895	Downie, Thomas	19, Oldhall Street, Liverpool
8th Feb., 1893	Duff, Peter	18, Radnor Place, Birkenhead
W. 13th Feb., 1878	**Duncanson, Thomas,** M. Inst. C.E. *Member of Council.*	16, Deane Road, Liverpool
25th Apl., 1900	Edge, Fred J., M. Inst. C.E.	City Engineer, Town Hall, Newcastle-on-Tyne
27th Jan., 1886	Edmiston, J. B., M. I. Mech. E., M.I.N.A.	Ivy Cottage, Highfield Road, Walton
2. 25th Sept., 1878	Ellington, Edward B., M. Inst. C.E.,	Palace Chambers, 9, Bridge Street, Westminster, London, S.W.
25th Feb., 1903	Ellis, Somers H.,	17, Priory Street, Birkenhead
11th Nov., 1896	Ellis, Edward, M. Inst. C.E.	Great Northern Railway, Leeds
1. 14th Jan., 1903	Ellison, A. R.	Hoscote, West Kirby
1. 27th Jan., 1886	Evanson, F. M.	9, Castle Street, Liverpool
28th Jan., 1903	Farrington, T. B.	Trinity Square, Llandudno
11th Mar., 1885	Ferber, E. G., M. I. N. A.	City of Dublin Steam Packet Co., 9, Regent Road, Liverpool
22nd Apl., 1896	Fernie, James	30, Brunswick Street, Liverpool
10th Jan., 1900	Ferranti, S. Z. de, M. Inst. C.E., M.I.E.E.	Hollinwood, Manchester
25th Nov., 1896	Field, Henry H.	Messrs. Rylands Bros., Warrington
11th Feb., 1880	Fitz-Gibbon, Gerald, M. Inst. C.E.	Aire & Calder Navigation, Leeds
10th Oct., 1886	Fosbery, A. C. W.	Assistant Engineer, Bombay Port Trust, Bombay
16th Nov., 1898	Fosbery, Charles Leslie	Harbour Works, Colombo, Ceylon
27th Jan., 1904	Fowke, T. M.	L. & N. W. Ry., Edge Hill, Liverpool
2. 13th Apl., 1898	**Fowler, A. F.,** M. Inst. C.E., M.I. Mech. E. *Vice-President.*	3, Cook Street, Liverpool
5th Dec., 1894	Fozzard, William C.	87, Walton Breck Road, L'pool
27th Apl., 1898	Francis, O. Francis	Electricity Works, Victoria Road, Kirkaldy
21st Nov., 1894	Fraser, Robert B.	Messrs. A. & R. Brown & Co., 90, Regent Road, Liverpool
16th Apl., 1902	Gaskell, Holbrook, A.M.I. Mech. E.	"Erindale," Frodsham, Cheshire
25th Nov., 1896	Gaskin, Fredk. Wm., Assoc. M. Inst. C.E.	Chapel Corner, Norley, Warrington

	DATE OF ELECTION	NAME	ADDRESS
	8th Feb., 1893	Geddes, Chris., M. I. Mech. E.	2A, Drury Lane, Water Street, Liverpool
	10th Feb., 1904	Gibbons, J. M.	18, Bidston Road, Oxton
	15th Nov., 1899	Given Ernest C., Assoc. M. Inst. C.E., A. M.I. Mech. E.	4, Hargreaves Road, Liverpool
1.	7th Nov., 1894	Glover, James, Junr., M.A., M. Inst. C.E.	Holly House, Lowton, Newton-le-Willows
	13th Feb., 1880	Glover, W. W. S.	"Gleddingholme," Beresford Road, Birkenhead
3.	6th Oct., 1880	Goldstraw, William	Building Surveyor, Municipal Buildings, Liverpool
	21st Nov., 1900	Goodacre, W. Geoffrey, A.M.I. Mech. E.	96, Stone Hill Road, Derby
	12th Nov., 1890	Goodwin, Gilbert S., M.I.N.A.	Alexandra Buildings, 19, James Street, Liverpool
	1st Dec., 1897	Grant, Allan J.	24, Victoria Place, Stoke, Devonport
	27th Jan., 1904	Gray, W. Turnbull	38, South Castle Street, Liverpool
	4th Apl., 1900	Grayson, H. M., M.I.N.A.	20, Water Street, Liverpool
	7th May, 1890	Greaves, R. M.	Wern, Tremadoc R.S.O., N. Wales
	19th Nov., 1902	Greenhough, James	"Marshville," 53, Derby Road, Farnworth, Near Widnes
	6th Apl., 1892	Griffith, T. H.	Lanzi, Campiglia, Maritima, Toscano, Italy
	9th Nov., 1892	Haarer, Ernest C., M.I. Mech. E.	Hydraulic Engineering Co., Ltd., African Chambers, Old Hall Street, Liverpool
	12th Nov., 1890	Hall, Watkin	Surveyor, District Council Offices, Great Crosby, near Liverpool
	31st Mar., 1897	Hallas, George H.	Huyton, near Liverpool
1.W.	18th Mar., 1891	Hamilton, Andrew, M.I.N.A.	c/o Messrs. G. S. Goodwin & Co., 19, James Street, Liverpool
	9th Mar., 1887	Hardaker, A. E.	Engineer's Office, L. & Y. Ry., Hunt's Bank, Manchester
	9th Mar., 1892	Harvey, Robert F., Assoc. M. Inst. C.E.	16, Seaton Buildings, 17, Water Street, Liverpool
1.S.	25th Nov., 1891	Haswell, Frederick J., M. I. Mech. E.	The Hull Hydraulic Power Co., Machell Street, Hull
	25th Apl., 1900	Hawkins, Elyot S., A.M.I. Mech. E.	General Manager, Colne Valley Ry., Halstead, Essex
	9th May, 1888	Hay, Arthur C., M.I.N.A.	9, Redcross Street, Liverpool
	25th Apl., 1900	Hay, William G.	201, North Hill Street, Liverpool
5.	28th Oct., 1885	**Hele-Shaw, H. S.**, LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M.I. Mech. E., F. R. Met. Soc. *Past President*—1894-95. (*Life Member.*)	The University, Liverpool
	13th Nov., 1895	Helliwell, Robt. B.	26, Winstanley Road, Waterloo
1.	5th Dec., 1900	Hidden, E. J.	F24, Exchange Buildings, L'pool
	15th Nov., 1899	Hide, W. J.	28, Hawarden Avenue, Sefton Park, Liverpool
	18th Nov., 1903	Hirst, John A.	Northgate Electrical Works, Chester
	30th Jan., 1901	Hobson, Walter D., Assoc. M. Inst. C.E.	Nantlle, Penygroes, R.S.O.
	19th Dec., 1900	Holland, Albert	Doonagore, via Lehinck, Co. Clare, Ireland
	19th Nov., 1902	Holliday, Edward	1, Hooton Road, Aintree

DATE OF ELECTION	NAME	ADDRESS
9th Nov., 1892..	Holliday, J. N. T.	Water Engineer's Department, Municipal Buildings, Liverpool
13th Jan., 1904...	Hollingsworth, E. M., A.M.I. Mech. E., A.M.I.E.E.	Grosvenor Road, St. Helens
13th Nov., 1895...	Holme, Arthur H., J.P., Assoc. Inst. C.E.	6, Gambier Terrace, Liverpool
8th Nov., 1882...	**Holmes, Arthur Bromley,** M. Inst. C.E., M.I.E.E. *Past President.*—1899-1900.	36, Princes Avenue, Liverpool
25th Apl., 1877...	**Holt, Alfred,** M. Inst. C.E. *Past President*—1881.	1, India Buildings, Water Street, Liverpool
13th Mar., 1901...	Holt, Charles F.	70, Drury Buildings, Water Street, Liverpool
3rd Feb., 1897...	Honiball, Charles R., M. I. Mech. E.	Maritime Engine Works, 10, Great Mersey Street, Liverpool
13th Nov., 1895...	**Hope, Alaric,** Assoc. M. Inst. C.E., A. M. I. Mech. E. *Member of Council.* (*Life Member.*)	Engineer's Office, Dock Yard, Liverpool
14th Nov., 1888...	Hope, W., J.P., Assoc. Inst. C.E.	10, Blackstock Street, Liverpool
13th Nov., 1895...	Horner, Joseph W.	42, Upper Fox Street, Leicester
4th Apl., 1900...	Horsburgh, S. Gordon	16, College Avenue, Great Crosby, near Liverpool
15th Nov., 1899...	Horsfall, W. M.	1, Hackins Hey, Liverpool
27th Jan., 1904...	Howarth, J. W.	55, Victoria Crescent, Eccles
12th Feb., 1890...	Howells, D. J.	c/o Engineering & Foundry Co., Ltd., Bellino-Fenderick, Odessa, Russia
10th Oct., 1877...	**Hudleston, Ferdinand,** M. Inst. C.E. *Past President*—1890-91.	25, Victoria Street, Westminster, London, S.W.
3rd Nov., 1886...	Hulme, E., Assoc. M. Inst. C.E.	51, North John Street, Liverpool
18th Nov., 1903...	Hunt, Louis J., Assoc. M. Inst. C.E., A.M.I.E.E.	c/o Sandycroft Foundry Co., Ltd., Chester
13th Jan., 1886...	Hurtzig, A. C., M. Inst. C.E.	2, Queen Square Place, Westminster, S.W.
18th Dec., 1901...	Ireland, J. D.	Black Diamond Street, Chester
18th Dec., 1901...	Isaac, B. Richard	45, South John Street, Liverpool
1st May, 1889...	Johnson, Joshua	1, Brompton Avenue, Sefton Park
7th Nov., 1894...	Johnson, W. B.	4, Clayton Square, Liverpool
20th Feb., 1889...	**Johnston, R. E.,** M. Inst. C.E. *Past President*—1892-93. (*Life Member.*)	Engineer's Office, Woodside Railway Station, Birkenhead
15th Jan., 1902...	Johnston, Robert W.	Borough Engineer's Department, Town Hall, Birkenhead
30th Jan., 1901...	Jones, A. Dansey, A.M.I. Mech. E.	L. & Y. Ry., Locomotive Department, Horwich, near Bolton
13th Nov., 1895...	Jones, Charles	14, Cranhurst Road, N., Mirden Green, London, N.W.
15th Jan., 1902...	Jones, Cosmo R.	Water Works Department, 109, Long Street, Cape Town
26th Feb., 1890...	Jones, I. M., M. Inst. C.E.	City Surveyor, Town Hall, Chester
12th Dec., 1888...	Jones, William	170, Walton Village, Walton
22nd Oct., 1879...	Jones, W. H., Assoc. M.Inst.C.E.,	Engineer's Office, Dock Yard, Liverpool
24th Feb., 1904...	Jones, W. P.	17, Welfield Place, Princes Park, Liverpool
24th Apl., 1895...	Keay, R. D.	3, Lee Park, Blackheath, London, S.E.

	DATE OF ELECTION	NAME	ADDRESS
	23rd Dec., 1891	Kelly, Archie	Elsinore, Promenade, Liscard
	10th Feb., 1904	Kemp, J. Pattison	Central Station, Mersey Railway, Birkenhead
	7th Nov., 1894	Kendall, Frank A.	Saxonhurst, Rock Ferry
I.D.	10th Apl., 1902	Kenyon, George Cecil Assoc. M. Am. Soc. C.E.	"Beaucoin," West Derby Village, Liverpool
	29th Apl., 1903	Kenyon, Francis, Assoc. M. Inst. C. E.	17, Priory Street, Birkenhead
1.	16th Nov., 1898	Ker, W. Arthur, Assoc. M. Inst. C.E.	c/o Messrs. Paterson, Cooper & Co., Ltd., Patella Works, Paisley, N.B.
1.	13th Jan., 1904	Kershaw, J. B. C., F.I.C., F.S.S.	West Lancashire Laboratory, Waterloo
	16th Jan., 1878	King, William, M. Inst. C.E.	5, Beach Lawn, Waterloo, nr. L'pool
	3rd Nov., 1886	Kinghorn, J. G., M.I.N.A.	Tower Buildings, Water Street, Liverpool
	21st Feb., 1900	Kirkland, George B.	Vauxhall Foundry, Banastre Street, Liverpool
	18th Nov,, 1903	Kirkpatrick, W. D., A.I.E.E.	Lincluden. Penkett Road, Liscard
	16th Apl., 1902	Knight, Henry Kirk	Sleaford, Lincolnshire
	20th Jan., 1897	Knowles, Thomas R.	Old Park Terrace, Wednesbury
	27th Apl., 1898	Larmuth, Luke H.	Assistant Civil Engineer, H.M, Dock Yard, Devonport
	30th Jan., 1901	Leech, Charles A.	
	9th Jan., 1887	Legg, W. A., M. Inst. C.E.	c/o Thos. Stewart, M. Inst. C. E., 6, St. George's Chambers, Cape Town
	31st Mar., 1897	Le Mesurier, Wm. Henry, M. Inst. C.E.	Dock Yard, Liverpool
	10th Feb., 1904	Le Tall, F. W.	c/o Messrs. British Insulated and Helsby Cables, Ltd., Prescot
	20th Jan., 1897	Lewis, Thomas	65, Hornby Road, Bootle
	21st Mar., 1900	Liardet, W. H.	10, Gambier Terrace, Liverpool
	15th Nov., 1899	Lipscomb, H. N.	Locomotive Department, Midland Railway, Liverpool
	14th Jan., 1903	Lind, Andrew L., A.I.E.E.	5, Cecil Road, Prenton, Birkenhead
	10th Jan., 1900	Lister, A. Hamilton	Hill Foot, Breeze Hill, Bootle
	27th Feb., 1901	Lynn, J. R. Dent	c/o John Lynn & Co., Ltd., St. Luke's Engine Works, Pallion, Sunderland
3.	7th June, 1876	Lyster, Anthony George, M. Inst. C.E.	Engineer-in-Chief, Dock Yard, Liverpool
	21st Nov., 1900	Macaulay, John	Public Health Dept., Municipal Buildings, Liverpool
	13th Nov., 1895	Mackenzie, James, M.I.N.A.	c/o Messrs. David Rollo & Sons, Fulton Engine Works, L'pool, N.
I.W.	22nd Nov., 1893	Macmuldrow, W. G. P.	P. O. Box 379, Cape Town, S. A.
	24th Feb., 1904	Macnab, J. F.	127, Crosby Road, Seaforth
6.	25th Apl., 1877	**Maginnis, Arthur J.,** M. Inst. C.E., M.I.N.A., M.I.M.E. *Past President*—1895-96.	28, Chapel Street, Liverpool
1.	18th Nov., 1903	Marchant, Professor E. W., D.Sc., A.M.I.E.E.	The University, Liverpool
	4th Apl., 1900	Marples, Ernest	"Kograh," Minstead Road, Gravelly Hill, Birmingham
	24th Jan., 1900	Marr, John J.	18, Moorfields, Liverpool
	16th Nov., 1898	Marsden, George Ellis	"Heyfield," Little Sutton, Cheshire

DATE OF ELECTION	NAME	ADDRESS
4th Nov., 1885	Mason, Charles	75, Gwendoline Street, Liverpool
2nd Dec., 1903	Maxwell, Lyon H.	c/o Messrs. Bruce & Still, Limited, 49, Sefton Street
16th Nov., 1898	McCulloch, A.	69, Wellington Avenue, Wavertree
16th Dec,, 1903	McHaffie, H.G.	27, Church Road, Hoylake
27th Nov., 1895	McIvor, W. T.	215 to 221, Cleveland Street, Birkenhead
2nd Dec., 1903	McLeod, R. S.	21, Victoria Avenue, Didsbury, Manchester
18th Nov., 1903	Meyer, H. S.	c/o British Thomson-Houston Co., Rugby
22nd Mar., 1893	Millar, Thomas	Walker Shipyard, Newcastle-on-Tyne
8th Nov., 1893	Miller, Henry	Council Offices, Heysham, Lancashire
). 8th Nov., 1882	**Miller, Thomas L.**, M.Inst. C.E., M.I. Mech. E., M.I.E.E. *Past President*—1903-04.	7, Tower Buildings N., Water Street, Liverpool
8th Nov., 1893	Mills, Frank, Assoc. M. Inst. C.E., A. M. I. Mech. E. (*Life Member.*)	"Taipeng," Perak, Malay Peninsula
9th Apl., 1879	**Mills, William E.** *Past President*—1885. *Member of Council.*	57, Hamilton Square, Birkenhead
4th Dec., 1901	Minns, R. J.	10, Gardner Rd., Tue Brook, L'pool
1st Dec., 1897	Molyneux, Thomas	City Engineer's Office, Municipal Buildings, Liverpool
27th Jan., 1904	Monkhouse, F. L.	The Well Fire Co., Paradise Street, Liverpool
7th Nov., 1894	Morison, D. B., M.I. Mech. E., M.I.N.A.	Messrs. T. Richardson & Sons, Engine Works, Hartlepool
15th Nov., 1899	Morris, E. A.	43, St. Mary's St., Peterhead, N.B.
16th Nov., 1898	Moulding, Thos., Assoc. M. Inst. C.E.	City Surveyor's Office, Exeter
4th Dec., 1901	Muckley, W. H., Wh. Sc., M.I. Mech. E.	Corporation Tramways, Lambeth Road, Liverpool
21st Mar., 1900	Muir, John R. M.	Messrs. H. & C. Grayson, Ltd., 179, Regent Road, Liverpool
21st Mar., 1900	Muir, William	Liverpool Fire Salvage Association, 16, Hatton Garden, Liverpool
21st Mar., 1900	Mulliner, E. B.	
16th Oct., 1889	**Musker, Arthur,** M. Inst. C.E., M. I. Mech. E. *Past President*—1901-02.	Simms Road, Tuebrook, Liverpool
11th Nov., 1896	Musker, Charles, Assoc. M. Inst. C.E.	Simms Road, Tuebrook, Liverpool
10th Jan., 1900	Naftel, Percy H.	18, Earlston Road, Egremont, Ches.
25th Apl., 1900	Nares, William G.	7, Howbeck Road, Oxton, B'head
10th Feb., 1904	Nash, R. P.	Prescot and District Electric Supply Station, Prescot, Lancs.
11th Nov., 1896	Neville, John U.	7, James Street, Liverpool
13th Nov., 1895	Newall, James	Messrs. J. Crosfield & Son, Warrington
22nd Nov., 1882	Newell, Thos. M., M. Inst. C.E.	Engineer, North Eastern Railway Company, Dock Office, Hull
11th Nov., 1896	Nicholson, James N., Assoc. M. Inst. C.E.	c/o Messrs. Wood & Fowler, 3, Cook Street, Liverpool
21st Mar., 1900	Norrie, William	47, Prescot Street, Liverpool
27th Jan., 1904	Norris, Wm., Assoc. M. Inst. C.E., M.I. Mech. E.	Lancashire Steam Motor Co., Leyland, Lancs.

	DATE OF ELECTION	NAME	ADDRESS
	9th Apl., 1902	O'Hanlon, James	Messrs. Crossley Bros., Limited, Brunswick Street, Liverpool
	14th Apl., 1897	Oglethorpe, W. A., M.I.N.A.	Engineer's Office, Dock Yard, Liverpool
	25th Nov., 1896	Oliphant, James	
	19th Nov., 1902	Owens, Harold	City Engineer's Department, Municipal Buildings, Liverpool
	4th Apl., 1900	Page James B.	20, Roxburgh Avenue, Aigburth
1.	5th Dec., 1877	**Pain, Coard S.**, Assoc. Inst. C.E., F.S.I. *Past President*—1886.	14, North John Street, Liverpool *Hon. Treasurer.*
2.	4th Apl., 1894	Parkin, John H., Assoc. M. Inst. C.E.	Corporation Waterworks, Gorpley Reservoir, Todmorden
	11th Mar., 1903	Parkinson, William Whiteside	94, Whitegate Drive, Blackpool
	25th Apl., 1900	Paterson, T. O., M. Inst. C.E.	26, Grosvenor Road, Claughton, Birkenhead
	30th Jan., 1901	Pickering, W. D.	Brunswick Foundry and Engine Works, 41, Sefton St., L'pool
1.	28th Feb., 1877	Pilkington, O. S., Assoc. M. Inst. C.E. *Life Member.*	Ivanhoe, Fferm Bach Road, Craig-y-don, Llandudno
	13th Nov., 1895	Pilling, S. W.	Welton Hall, Brough, East Yorkshire
	9th Nov., 1892	Platt, S. S., M. Inst. C.E.	Borough Surveyor, Rochdale
	4th Apl., 1900	Pocklington, Fred. A.	Freshfield, near Liverpool
1.	9th Mar., 1887	Pooley, Henry, Jun.	Albion Foundry, Harecastle Junction, Stoke-on-Trent
	2nd Mar., 1898	Pooley, J. S.	Albion Works, 25, South Kinning Place, Paisley Road, Glasgow
3.	28th Feb., 1877	Potts, John J., Assoc. M. Inst. C.E.,	Pier Office, Southport
	16th Mar., 1881	Price, Joseph, Assoc. M. Inst. C.E., M. I. and S. Inst.	125, Bunhill Row, London, E.C.
1.	1st Dec., 1886	**Priest, Frank E.**, M. Inst. C.E. *President.*	13, Harrington Street, Liverpool
2.S.	3rd Mar., 1897	Pritchard, P. M., Assoc. M. Inst. C.E., Assoc. M. Am. Soc. C.E.	52, Upper Parliament Street, Liverpool
	4th Apl., 1900	Ransome, G. F.	67, Tithebarn Street, Liverpool
	20th Oct., 1886	Rathbone, A. L., Assoc. M. Inst. C.E. (*Life Member.*)	Greenbank, Liverpool
	16th Jan., 1901	Rathmell, Bernard	16, Parkfield Drive, Liscard
1.D.	1st Dec., 1897	Reade, M. Treleavan	2, South John Street, Liverpool
	6th Dec., 1893	Reeves, Wilfred	"Craigairne," Donegal Park, Antrim Road, Belfast
	23rd Jan., 1889	Richardson, R.	82, Devonshire Road, Liverpool
	12th Feb., 1902	Ridge, Thomas	Llanfechain, North Wales
	15th Jan., 1902	Rhodes, Ernest H.	Hazel Brae, Market St., Hoylake
	21st Nov., 1900	Roberts, Cecil H.	72, Serpentine Road, Birmingham
	20th Nov., 1901	Roberts, H. J., M.I. Mech. E.	42, Castle Street, Liverpool
	6th Apl., 1892	Roberts, R. O. Wynne	Water Engineer, Cape Town, S.A.
	19th Nov., 1902	Roberts, Walter S.	Railway Signal Co., Fazakerley
	24th Jan., 1900	Robinson, Alex. H., A.M.I.E.E.	Hawthorne House, Oak Hill Park, Liverpool
	7th Nov., 1894	Robinson, J. P.	Springfield Iron Works, Salford, Manchester
	24th Oct., 1894	Robinson, W. H.	

DATE OF ELECTION	NAME	ADDRESS
1st Dec., 1897	Rogers, Hugh, M. Inst. C. E.	Engineer's Office, Dock Yard, Liverpool
24th Feb., 1904	Rosenheim, E. A., B. Sc. A.M.I.E.E.	1. Croxteth Road, Liverpool
21st June, 1876	**Ross, Alexander,** M. Inst. C.E. *Past President*—1880.	Engineer's Office, Great Northern Railway, King's Cross, London
11th Feb., 1903	Ross, M. Glen.	27, Handfield Road, Waterloo, near Liverpool
W. 5th Dec., 1894	Rowland, William, Wh. Sc.	
12th Nov., 1890	Rowlandson, C. A., M.Inst.C.E.	Great Central Railway, M'chester
30th Oct., 1889	Rowlandson, W.	140, Boundary Street, Liverpool
13th Nov., 1889	Royston, Ernest R.	15, Water Street, Liverpool
27th Sept., 1880	Rubery, John T.	Victoria Ironworks, Darlaston, Staffordshire
9th Nov., 1892	Russell, H. F.	Vine House, Neston, Cheshire
7th Nov., 1894	Rutherford, A., M.I.N.A.	Neptune Works, Bridge Street, Birkenhead
21st Feb., 1900	Rutherford, W.	Messrs. Dick Kerr and Co., 110, Cannon Street, London, E.C.
19th Nov., 1902	Salter, J. R.	40, North John Street, Liverpool
25th Sept., 1878 / 17th Nov., 1897	**Salmon, Frank B.,** M. I. and S. Inst. *Past President*—1882.	African Chambers, Oldhall Street, Liverpool
17th Nov., 1897	Salmon, Harry	Stranton Works, West Hartlepool
3rd Nov., 1886	Saner, J. A.	Weaver Navigation, Northwich
9th Mar., 1892	Saunders, S. H.	14, Woodland Road, Dacre Hill, Rock Ferry
21st Feb., 1900	Schultz, Charles S.	Messrs. Dick Kerr and Co., 110, Cannon Street, London, E.C.
13th Nov., 1895	Scott, Wm. G., M. Inst. C.E.	26, Dingle Lane, Liverpool
10th Jan., 1900	Sharp, John, M.I. Mech. E., M.I. & S. Inst.	Bolton Iron and Steel Company, Limited, Bolton
15th Jan., 1890	Sharrock, C. W.	The Linthurst, Montalt Road, Woodford Green, London, N.E.
19th Nov., 1902	Shaw, Joshua	Engineer's Office, Mersey Railway, Central Station, Birkenhead
12th Mar., 1884	Shawcross, H. J., B.E., Queen's University, Ireland	Water Engineer's Department, Municipal Buildings, Liverpool
25th Apl., 1900	Sherley-Price, E. A.	Albert Chambers, Albert Square, Manchester
13th Dec., 1899	Shield, Henry, M. Inst. C.E.	Messrs. Fawcett, Preston & Co., York Street, Liverpool
28th Mar., 1883	Sinclair, John S., Assoc. M. Inst.C.E.	Surveyor's Office, Town Hall, Widnes
7th Nov., 1894	Sloan, Robert A., Wh. Sc., M.I. Mech. E.	34, Castle Street, Liverpool
21st Mar., 1900	Smith, A. G.	66, Falkland Road, Egremont, Cheshire
16th Jan., 1884	Smith, Aston W.	Gadley, Buxton
25th Jan., 1888	**Smith, J. Reney,** M.I. Mech. E., M.I.N.A. *Vice-President.*	Messrs. H. & C. Grayson, Ltd., 179, Regent Road, Liverpool
13th Jan., 1904	Snoxall, G. E., M.I. Mech. E.	16, Merton Grove, Bootle
10th Nov., 1875	Squire, W. W., M. Inst. C.E.	Bristol Docks, Engineer's Office, Cumberland Basin, Bristol
4th Nov., 1885	Stead, Edward J.	Assistant District Engineer, Public Works Department, Durban, Natal, South Africa

	DATE OF ELECTION	NAME	ADDRESS
	4th Dec., 1901	Stead, Wm.	Hey House, Preston Avenue, Eccles
1.	20th Nov., 1901	Steele, F. W.	c/o Messrs. C. & A. Musker, Ltd., Simms Rd., Tue Brook, L'pool.
	12th Jan., 1887	Stephenson, E. P., Assoc. M. Inst. C.E.	Surveyor's Office, District Council Offices, Llandudno
	18th Nov., 1903	Stevenson, C. Maxwell	Howarth's Buildings, Cross Street, Manchester
	6th Mar., 1895	Stott, Thomas B. *Life Member.*	Woodseat, Eastham, Cheshire
	13th Apl., 1898	Strongitharm, H. H.	14, Cook Street, Liverpool
	23rd Nov., 1892	Sutcliffe, Fielden	York Lodge, Crosby Road South, Seaforth
1.	26th Feb., 1890	Taylor, A. Lester, M.I.E.E.	1, Fowell Road, New Brighton, Cheshire
	13th Dec., 1899	Taylor, E. Sydney	Sandycroft Foundry, Hawarden, Flintshire
	7th Mar., 1900	Taylor, James, M.I.E.E.	Heathercliffe, Helsby, Near Warrington
1.	4th Apl., 1900	Taylor, J. Reginald, Stud. Inst. C.E.	11, Vincent Square, Westminster, London, S.W.
	12th Mar., 1902	Taylor, Ralph Pierce	The General Supply & Construction Co., 8/10, Bridge St., New York
	25th Mar., 1903	Tennant, James,	16, Station Road, Prescot
	26th Oct., 1892	Terry, Stephen H., M. Inst. C.E., M.I. Mech. E.	17, Victoria Street, Westminster, London, S.W.
	9th Mar., 1604	Thomas, Eustace, B.Sc.,	c/o Bertram Thomas, Worsley Street, Hulme, Manchester
	7th Mar., 1900	Thompson, F. G.	H. & C. Grayson, Ltd., Regent Road, Liverpool
	21st Mar., 1900	Thompson, H. Ellis	
	30th Nov., 1898	Thomson, G. Carruthers	53, Bedford Road, Rock Ferry
	13th Feb., 1901	Thornton, S. E., Assoc. M. Inst. C.E.	Sanctuary House, Tothill Street, Westminster, London, S.W.
	8th Mar., 1893	Tickle, John J.	Claughton Chambers, Hardshaw Street, St. Helens
	7th May, 1890	Timmins, Arthur, Assoc. M. Inst. C.E.	Argyll Lodge, Runcorn
	19th Nov., 1902	Tiplady, C. E.	Gold Coast Government Ry., Asst. Engineer's Office, Dunkua, W.C.A.
	20th Nov., 1901	Tod, P.	c/o Messrs. E. H. Williamson & Co., Lightbody Street, L'pool
	22nd Jan., 1896	Travers, W. H.	Engineer's Department, Public Offices, Egremont, Cheshire
4.	25th Apl., 1877	Tudsbery, J. H. T., D. Sc., M. Inst. C.E.	Institution of Civil Engineers, 25, Great George Street, Westminster, London, S.W.
	26th Feb., 1902	Tunstall, Jas. W.	School House, Caledonia St., L'pool
	24th Jan., 1900	Turton, F. T.	Deputy Surveyor, Municipal Buildings, Liverpool
	11th Dec., 1895	Urquhart, R. J., A.M.I. Mech. E.,	Central Chambers, South Castle Street, Liverpool
	5th Nov., 1902	Varley, Geo. P.	Waterloo Foundry, St. Helens, Lancashire
	25th Jan., 1899	Vicars, Thomas	The Knoll, Newton-le-Willows, Lancashire
	19th Nov., 1902	Vickers, Arthur	11, Longmoor Lane, Aintree
	20th Oct., 1886	Vickess, Samuel, Jun.	54, Falkner Street, Liverpool
1.	26th Feb., 1890	Von Sobbe, F. A., Assoc. M. Inst. C.E.	3, Belvidere Road, Liverpool

DATE OF ELECTION	NAME	ADDRESS
26th Apl., 1899	Wade, J. Arthur	27, Kremlin Drive, Stoneycroft, Liverpool
27th Jan., 1886	Wakem, Peter H.	6, Prescot Drive, Newsham Park, Liverpool
27th Jan., 1904	Wallace, W. G.	c/o British Thomson-Houston Co., Manchester
21st Mar., 1900	Warburton, W. H.	166, Longmoor Lane, Aintree
3rd Nov., 1886	Ward, E. T., Assoc. M. Inst. C.E.,	Hillside, Beech Road, Northwich
25th Nov., 1896	Watson, R. W.	30, Devonshire Road, Liverpool
11th Dec., 1889	Weatherilt, Arthur	Knowsley View, 24, Denton's Green Lane, St. Helens
8th Nov., 1893	Webb, Walter H.	2, Boundary Road, Birkenhead
7th Dec., 1881	**Webster, John J.**, M. Inst. C.E. *Past President*—1887.	39, Victoria Street, Westminster, S.W.
18th Feb., 1891	Wells, J. M.	London Hydraulic Power Co., Palace Chambers, 9, Bridge Street, Westminster, S.W.
25th Nov., 1896	West, Charles H., M.I.M.E.	5, Castle Street, Liverpool
25th Feb., 1885	**West, Henry H.**, M. Inst. C.E., M.I.N.A., M. I. Mech. E. *Past President*—1889-90. *Member of Council.*	British and Foreign Chambers, 5, Castle Street, Liverpool
8th Nov., 1893	Westharne, Henry G.	4, Kimberley Street, Liverpool
7th Mar., 1900	Whalley, Alfred, M.I.E.E.	Ashville, Helsby, Near Warrington
11th Nov., 1896	Wheeler, Percy	Oldbury Railway Carriage Company, Birmingham
15th Nov., 1899	Wheelton, S. J.	City Engineer's Office, Municipal Buildings, Liverpool
17th Nov., 1897	White, Joseph Walwyn	Huntley, Hunt's Cross, near Liverpool
14th Dec., 1898	Whittaker, F. W.	The Bradford Dyers' Association, Ltd., 39, Well Street, Bradford
19th Oct., 1887	**Wilcox, Ernest S.**, M. Inst. C.E. *Past-President*—1902-03.	The Bents, New Brighton
26th Apl., 1899	Wilding, James	Surveyor's Office, Town Hall, Runcorn
24th Jan., 1900	Wilkie, James B.	c/o Messrs. Elder, Dempster & Co., 56, Jamaica Street, Liverpool
18th Nov., 1903	Williams, Daniel	Town Hall, Atherton
3rd Dec., 1902	Williams, R. J.	16, Lord Street, Liverpool
4th Apl., 1900	Williamson, Gordon	5, St. Mary's Terrace, Waterloo
13th Nov., 1895	Williamson, James	Engineer's Offices, Cambrian Railway Company, Oswestry
29th Apl., 1903	Wilson, Alexander C., Assoc. M. Inst. C.E.	17, Priory Street, Birkenhead
30th Nov., 1898	Wilson, Henry B.	45, Derby Road, Farnworth, Widnes
12th Mar., 1902	**Wilson, H. W.**, A.M.I.E.E. *Member of Council.*	Messrs. T. L. Miller & Wilson, 19, Brazennose Street, Manchester
3rd Feb., 1897	Wilson, John	7, Beech Road, Higher Tranmere, Birkenhead
5th Dec., 1900	Winder, Oliver, Assoc. M. Inst. C.E.	Ely House, Newton Heath, Manchester
28th Jan., 1880	Window, Edmund R., Assoc. M. Inst. C.E.	
19th Nov., 1902	Wolfenden, B. J., Assoc. M. Inst. C.E.	64, Merton Road, Bootle
13th Nov., 1895	Wood, Herbert	26, Windsor Road, Tue Brook, Liverpool

DATE OF ELECTION	NAME	ADDRESS
13th Feb., 1878 22nd Oct., 1884	**Wood, John Thomas,** M. Inst. C.E. *Past President*—1891-92.	Halewood, near Liverpool
25th Apl., 1900	Wood, William Brownbill	The Court, Halewood, Nr. L'pool
12th Jan., 1887	Woodall, Corbet, M. Inst. C.E.	Palace Chambers, Bridge Street, Westminster, S.W.
28th Jan., 1903	Woods, Edwin	Latchford, near Warrington
11th Jan., 1893	**Woods, Arthur R. T.,** M.I.N.A. *Member of Council.*	c/o Messrs. Nelson & Co., 20, Castle Street, Liverpool
4th Apl., 1900	Woollright, Percy	8, Croxteth Road, Liverpool
18th Dec., 1901	Worthington, W. B., B. Sc., M. Inst. C.E., M.I. Mech. E.	Lanc. & Yorks. Railway Engineer's Office, 10, Gt. College Street, Westminster, S.W.
7th Feb., 1900	Wright, Robert	Messrs. Thomas Downie & Co., Toxteth Engine Works, Caryl Street, Liverpool
21st Feb., 1900	Wright, W. Ryle	Borough Electrical Engineer, Wellington, New Zealand
19th Nov., 1902	Wyles, David D., M. I. Mech. E.	1, Rutland Avenue, Sefton Park
22nd Feb., 1899	Yates, F. Spencer, Assoc. M. Inst. C.E.	Town Hall, Waterloo, Nr. L'pool
4. 10th Nov., 1875	**Yeatman, Morgan E.,** M.A. Cantab., M. Am. Soc. C. E., *Past President*—1879.	Messrs. S. Pearson & Son, Ltd., 10, Victoria Street, S.W.
1. 24th May, 1876	Yerburgh, J. E., Assoc. Inst. C.E.	Wavendon Lodge, Woburn Sands, R.S.O., Bedfordshire
14th Jan., 1880	Ziffer, Fredk. Henry (*Life Member.*)	

432 Total Number of Members

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

ASSOCIATE MEMBERS.

DATE OF ELECTION	NAME	ADDRESS
3rd Dec., 1902	Edmondson, Jas. H.	Landgate, Brynn, near Wigan
6th Apl., 1904	Holmes, Geo. N.	"Clifton," Egremont Promenade, Egremont, Cheshire
19th Nov., 1902	Houghton, H. Johnson	Westward, Neston, Cheshire
18th Nov., 1903	Jackson, G. J.	"Westborne," St. Anne's-on-Sea
9th Nov., 1902	Mason, Arnold S., Stud. Inst. C. E.	Water Engineer's Department, Municipal Buildings, Liverpool
9th Mch., 1904	Meiklejohn, James H.	4, Devonshire Street, Ardwick, Manchester
29th Apl., 1903	Montague, J. E. Stud. Inst. C. E.	17, Priory Street, Birkenhead
3rd Dec., 1902	Owens, F. J.	20, Church Street, Egremont, Cheshire
7th Dec., 1902	Taylor, W. F.	Acresfield, Nicholas Road, Blundellsands
9th Nov., 1902	Williams, Harold C., B.A.	4, Derwent Square, Stoneycroft
7th Dec., 1902	Wilton, T. R.	143, Hartington Road, Sefton Park, Liverpool

11 Total Number of Associate Members

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

ASSOCIATES.

DATE OF ELECTION	NAME	ADDRESS
13th Dec., 1899	Alcock, Charles	Royal Insurance Company, 1, North John Street, Liverpool
6th Apl., 1892	**Annett, R. C. F.**, Assoc. Inst. C.E., *Honorary Secretary.*	4, Buckingham Avenue, Sefton Park, Liverpool
30th Nov., 1898	Arnison, R. Frank	2, Gilda Crescent Road, Eccles, near Manchester
21st Mar., 1900	Banner, J. S. Harmood	Ashfield Hall, Neston, Cheshire
25th Jan., 1899	Barrow, Richard	6, Caroline Place, Claughton, Birkenhead
15th Jan., 1902	Bentley, Francis	c/o Messrs. Isaac Bentley & Co., Adelphi Works, Salford, Manchester
18th Nov., 1903	Blake, L. R. S. C.	c/o British Thomson-Houston Co., Manchester
2nd Mar., 1898	Bremner, W. T.	197, Great Howard Street, L'pool
6th Jan., 1897	Burrows, Freeman	Bayford House, Sutton, Surrey
11th Nov., 1891	Burrows, Herbert F.	8, India Buildings, Fenwick Street, Liverpool
26th Feb., 1902	Butterworth, E. W.	African Chambers, Old Hall Street, Liverpool
10th Jan., 1900	Cohen, Louis S., C.C.	The Priory, St. Michael's Hamlet, Liverpool
10th Jan., 1900	Dart, Richard, C.C.	Aigburth Drive, Liverpool
14th Jan., 1903	Davies, Peter	8, Cook Street, Liverpool
11th Nov., 1896	Docker, Frank Dudley	The Gables, Kenilworth
11th Nov., 1896	Docker, Ludford C.	Icknield Port Road, Birmingham
13th Dec., 1899	Dove, John M.	Liverpool and London and Globe Insurance Co., Dale St., Liverpool
21st Nov., 1900	Edmiston, James M.	Ivy Cottage, Highfield Road, Walton
16th Nov., 1898	Edmondson, Robert Holt	Bryerswood, Windermere
19th Nov., 1902	Emery, Walter T.	Municipal Technical School, Byrom Street, Liverpool
30th Oct., 1895	Glover, J. H.	Bank Chambers, 60, Castle Street, Liverpool
19th Nov., 1902	Gossage, W. Winwood	Messrs. Wm. Gossage & Sons, Ltd., Widnes, Lancashire
13th Dec., 1899	Higginbottom, S. W., C.C.	African Chambers, 19, Old Hall Street, Liverpool
4th Apl., 1900	Houlding, William, C.C.	10, Eaton Road, Cressington Park, near Liverpool
16th Nov., 1898	Hughes, Robert John	Surveyor, District Council Office, Penmaenmawr, North Wales
4th Apl., 1900	Jackson, Thomas H., J.P.	Manor House, Birkenhead
13th Dec., 1899	Jones, Sir Alfred L., K.C.M.G., J.P.	Messrs. Elder, Dempster & Co., Water Street, Liverpool
21st Mar., 1900	Jones, Frank	32, Daulby Street, Liverpool
19th Dec., 1900	Jones, William	10, Great Mersey Street, Liverpool

DATE OF ELECTION	NAME	ADDRESS
13th Mar., 1901	Kelly, J. Dunbar	B, Queen Insurance Buildings Dale Street, Liverpool
11th Nov., 1896	Littler, Henry	Architect's Dep't, County Offices, Preston
18th Nov., 1903	Lloyd, T. Percival	43, Ullet Road, Liverpool
7th Feb., 1900	Low, John	110, Sheil Road, Liverpool
4th Apl., 1900	Macaulay, John	General Manager, Newport Alexandra Docks & Ry. Co., Newport, Mon.
11th Dec., 1895	Maples, Cecil E.	14, Cook Street, Liverpool
12th Feb., 1902	Maples, Herbert A.	3, Cook Street, Liverpool
15th Nov., 1899	Martin, L. W.	22, Sir Thomas Street, Liverpool
24th Feb., 1904	Martin, Howard E.	38, Elgin Drive, Liscard, Cheshire
25th Jan., 1899	Maxwell, M. H., Junr., J.P.	76, Canning Street, Liverpool
13th Nov., 1895	McClure, Wm. Lees, J.P.	Ivy Bank, Huyton
11th Mar., 1903	Moore, G. A., A.I.E.E.	Engayne, Spital, Bromborough
27th Nov., 1895	Nicholson, A. C., F.G.S.	12, Salop Road, Oswestry
17th Nov., 1897	Oppenheim, H. S., J.P.	St. Helens, Lancs.
29th Nov., 1899	Palethorpe, James Arthur	
12th Feb., 1902	Pearce, W. R.	Messrs. Frank Pearce & Co., 18, Chapel Street, Liverpool
15th Nov., 1899	Petrie, Sir Charles, J.P.	7, Devonshire Road, Princes Park
.W. 8th Feb., 1893	**Pierce, Ernest W.** *Honorary Solicitor.*	Deputy Town Clerk, Municipal Buildings, Liverpool
10th Jan., 1900	Richardson, W.	North British & Mercantile Insurance Co., Tithebarn St., L'pool
13th Dec., 1899	Rutter, Frederick W. P.	London & Lancashire Fire Insurance Co., Dale Street, Liverpool
8th Nov., 1893	Shone, J. Fowler	24, Fenwick Street, Liverpool
16th Jan., 1901	Somerville, F. J.	24, Fenwick Street, Liverpool
8th Nov., 1893	Temple, John *(Life Associate)*	Warrington Wire Rope Co., 13, Goree Piazzas, Liverpool
14th Jan., 1903	Thomson, William	7, Cook Street, Liverpool
20th Nov., 1901	Wheeler, A. Henry	The Tower, Trevor, Carnarvon
26th Apl., 1899	White, Herbert	Messrs. R. White & Sons, Widnes
31st Jan., 1894	Worrall, Ernest, M.S.I.	Surveyor, Old Trafford, near Manchester
1. 17th Mar., 1897	Young, Oswald W.	Egerton Park, Rock Ferry

57 Total Number of Associates

N.B.—For the convenience of members wishing to communicate with the Hon. Secretary upon matters pertaining to the Society, time will be saved by addressing him at his private residence, as above given.

STUDENTS.

	DATE OF ELECTION	NAME	ADDRESS
	16th Nov., 1898	Adamson, Richard A.	Liverpool Corporation Water Works, Horwich, near Bolton
	25th Mar., 1903	Aylward, Richard N.	Oakhill, Rock Ferry, Cheshire
	21st Nov., 1900	Beloe, Wilfrid, Stud. Inst. C.E.	11, Livingston Drive, Sefton Park, Liverpool
	16th Apl., 1902	Denbigh, Edward Bisset	87, Crosby Road, Seaforth, near Liverpool
	21st Mar., 1900	Duncanson, Alec. W., B.Sc., Stud. Inst. C. E.	16, Deane Road, Liverpool
1.	24th Jan., 1900	Flinn, Hugo	15, Highfield Street, Liverpool
	11th Nov., 1903	Galloway, J. Bruce	31, Crosby Road, Birkdale, Southport
	21st Mar., 1900	Giles, Humphrey N., B. Sc., Stud. Inst. C. E.	6, Gambier Terrace, Liverpool
	11th Dec., 1895	Hatton, Ernest	Tramways Engineer, Town Hall, Salford
1.	15th Nov., 1899	Leighton, Arthur, Stud. Inst. C.E.,	7, Oxford Road, Birkdale
	11th Feb., 1903	Miller, John W. A.	49, Westbank Road, Devonshire Park, Birkenhead
	5th Dec., 1900	Mitchell, Alex. C., Junr. Stud. Inst. C. E.	Weston House, Halewood
	19th Feb., 1904	Nicholson, E. D.	12, Salop Road, Oswestry
	18th Nov., 1903	Shelmerdine, Eric D. S., Grad. I. Mech. E.	Glady's Mount, Stretford, Manchester
	21st Mar., 1900	Stott, Harold	106, Upper Stanhope Street, Princes Road, Liverpool
	17th Dec., 1902	Shawe, J. W.	Bank House, Ormskirk, near Liverpool
	10th Jan., 1900	Tippett, Philip V.	c/o The Farrel Foundry and Machine Co., Ansonia, Conn., U.S.A.
	4th Apl., 1900	Tredcroft, A. F., Stud. Inst. C.E.,	26, Rock Lane West, Rock Ferry
	18th Nov., 1903	Ward, H. Bernard, B. Sc.	The Elms, West Kirby
	18th Dec., 1901	Webb, James Tregenna	Contractor's Office, New Destructor Works, Castle Street, Northampton
	25th Apl., 1900	Whittington, William E.	44, Arnold Street, Liverpool
	24th Jan., 1900	Wollaston, C. H. P.	166, Longmoor Lane, Aintree

22 Total Number of Students

531 Total Number of Members, Associate Members, Associates and Students

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LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

FIRST MEETING—4TH NOVEMBER, 1903.

MR. ERNEST S. WILCOX, M.Inst. C.E.,

The Retiring President,

INTRODUCED TO THE MEETING

Mr. T. L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

The President-Elect,

WHO THEREUPON TOOK THE CHAIR.

INAUGURAL ADDRESS.

GENTLEMEN,

My first duty, as well as my privilege, this evening, is to thank you most heartily for the honor you have conferred upon me in electing me your President for the ensuing Session. It is a compliment which I greatly appreciate, and I sincerely trust I may be enabled, with the assistance of my colleagues on the Council, to so discharge the duties of the post as to preserve the dignity and traditions of the Society, and to promote in every way in my power its best interests.

It is customary for a Presidential Address to be a review of the progress or development of the particular branch of the Profession with which the President and Members of the Society may be more particularly concerned, and this being so, and as the cheap supply of power is a matter which vitally concerns the industrial welfare of the country, I have ventured to take up this evening the question of the Cost of the Production of Power, in the hope that a review of what has already been done may have the effect of directing greater attention to this most important question.

In considering the sources of energy on which we may draw for mechanical power, I propose dealing very briefly with :—

(1) Tidal and Wave Energy.

(2) Wind.

(3) Water.

(4) Fuel.

Of these sources of energy the first, though enormous in amount is practically untouched ; the second is only used to a very small extent ; while the third and fourth play a very important part in the supply of power for industrial purposes.

TIDAL AND WAVE ENERGY.

One of the most alluring and, at the same time, one of the most disappointing of the possible sources of energy is that of harnessing the tides as to obtain power from their rise and fall. Here and there attempts on a small scale have from time to time been made to utilise the enormous store of tidal power, but the amount of success attained has been most disappointing. The intermittent nature of the tidal current, the comparatively small range of the rise and fall available, and the very large extent of storage area required, all combine to restrict the attempt to utilise tidal energy to a few favoured localities, where, through the natural configuration of the ground, the necessary reservoirs can be constructed at small capital cost, and where the rise and fall of the tides are sufficiently great to permit of an adequate return on the capital expended on the necessary works.

In dealing with this matter, it may be pointed out that in order to continuously utilise the tidal energy, two reservoirs at different levels are necessary, the reservoirs being separated by a bank above high water within which turbines would be fixed. During the higher one-third of the tidal range, while the tide is rising, the upper reservoir would be placed in communication with the sea, and in like manner the lower reservoir would be placed in communication with the sea during the lower one-third of the tidal range, while the tide is falling. If, then, H be the range in feet, the upper reservoir would never fall below $2/3\ H$ measured from low water, and the level in the lower reservoir would never rise above $1/3\ H$. Plotting the available head for all ranges of the tide, it is found that it varies from $0{\cdot}53\ H$ to $0{\cdot}80\ H$, the mean value being $2/3\ H$; and that the gross horse power is given by the expression H.P. $= \frac{S\,H^2}{30}$ where S = the area of each reservoir in acres. Or assuming a tidal range of 10 feet—

and the neap tide must be taken if there is a constant demand—0·3 acre, or 1452 square yards area for each reservoir, must be provided for each horse power demanded. This, of course, except in very exceptional circumstances is prohibitive, and there are in consequence very few examples, and those only on a very small scale, where this source of energy is being utilised.

Another source of energy which appeals strongly to the popular imagination is the utilisation of the energy of the waves, but here again the difficulties to be encountered with are almost insuperable, as although the energy of the waves is very great, it is most irregular in amount and requires very large apparatus for its utilisation. The power, again, is very intermittent, and the periodicity of the wave motion is so low that in order to utilise the energy in anything like a steady manner it is necessary to provide some means of storage, which greatly reduces the efficiency and adds to the cost. This being so, there appears to be little chance of any great developments in the utilisation of the energy of the waves, especially while the other sources of energy, to which attention will presently be directed, are available.

WIND.

From the very earliest times wind has been employed as a prime mover, but only on a very limited scale. As a cheap source of power wind holds a very high position, but unfortunately its extreme irregularity, the very large sail area required for but moderate powers, and the fact that the speed of rotation depends upon the velocity of the wind, which is very variable, militates greatly against its extended use as a source of power for industrial purposes. As an example of the sail area required, it may be pointed out that with a breeze of 10 miles per hour a wheel about 25 feet in diameter is required to produce one effective horse power, and that even then the rate of rotation, about 30 revolutions per minute, is inconveniently low for many purposes. It appears, therefore, that for any but very small work, wind power is altogether out of the question, and need not therefore be further discussed here.

WATER.

Under favourable conditions "water power" delivered from streams stands unrivalled as a cheap source of energy for industrial purposes. As a rule, however, it lies away from old manufacturing centres, from which industries are slow to move. In the nature of things water powers are usually found in hilly

districts, whereas manufacturing industrial centres are for the most part situated in districts where, in addition to the supply of cheap power, there must be ample facilities for obtaining raw materials and for distributing the manufactured goods. As a matter of fact, in most industries the cost of power bears a much smaller proportion to the total costs than is generally supposed, and we consequently find that instead of the industries going to the neighbourhood of the water fall, the power from such fall is in many instances transmitted to the industrial centres. This is particularly the case in Canada and the States, where electrical energy generated at water power stations is transmitted distances up to 220 miles to industrial centres.

In water power stations the annual cost of power is made up principally of the charges for interest and for writing off the capital outlay, in addition to, in some instances, a royalty for the use of the water rights, which varies according to circumstances, being in most instances just sufficient to bring the cost of the water power below its established rival in the district—for it must be remembered that in this question of power production, as in the supply of commodities generally, that the value of a product is the price that it will bring in the open market. In dealing with this phase of the subject, however, one fact must be kept prominently in view, and that is, that while power obtained from fuel depends upon the cost of fuel, into the available supply of which we are yearly making greater inroads, the supply of water power is practically independent of other than capital charges and the royalties above mentioned, and that it can therefore be supplied with certainty at a fixed rate, day and night, from year end to year end, provided we deal with the minimum supply alone.

Of the world's total water power supply we know little. It may, however, be pointed out that France uses water power to the extent of * 500,000 Horse Power ; that in the United States the total horse power of the improved water power is approximately † 1,500,000 ; that in Norway it is estimated that ‡ 263,000 Horse Power could be supplied by the larger rivers, south of Trondhjem, without regulation, and that by regulation the power could probably be quadrupled ; and that for electro-chemical works alone it was estimated in 1890 that stations of a capacity of 200,000 Horse Power

* Presidental Address.—Mr. J. C. Hawkshaw, Proc. Inst. C.E., Vol. CLI.
† "Electric Power Transmission."—Dr. Louis Bell.
‡ Howard Lectures on Development and Transmission of Power from Central Stations, by Professor Unwin.

were established. In addition to this, Canada, Africa, India and South America, have each a vast amount of water power in store for the future, which in course of time will doubtless all become centres of industry and manufacture.

The chief difficulty in the way of utilising water power for industrial purposes is the variation in the supply of water, which depends in large measure upon the seasons, and it thus becomes necessary in estimating the power available to consider the minimum flow, and for this purpose the records of a number of years are necessary.

In some cases local conditions are so favourable that water power can be developed at an almost nominal cost. In other cases unforseen circumstances have so enhanced the cost of development as to make the cost of water power greater than that of steam power. According to Professor Janet the cost of water power development in France varies from £4·28 per H.P. to £30 per H.P., depending on the head to be dealt with, the lowest expenditure being upon a fall of 140 metres in Haute-Savoie, the H.P. being calculated at the turbine shaft.

At Geneva, for the first group of turbines erected, of 840 H.P., and for the river works then completed, the capital cost amounted to £60 per effective H.P. The groups of turbines subsequently erected have cost but £19 per H.P., and the completed works will cost but £27 per H.P.

At Vonvray water power electric works, on the left bank of the Rhone, the total cost of the first 2,000 H.P., including water rights, was £32 per H.P. A second 2,000 H.P. necessitating only the construction of new conduit 370 yards long, and four new generating sets, will bring down the cost of the whole station to £11 per H.P. From an examination of a considerable amount of data regarding the cost of water power development the highest capital expenditure appears to have been at Lyons, where it amounted to £84 per H.P. developed, over one-half of this amount being expended upon hydraulic engineering works. At the Chlorate works at Vallorbe, on the other hand, the capital expenditure upon the development of 3000 H.P. amounted to but £3·89 per H.P.

Dealing now with the charges for power, Mr. Zolly, of the firm of Escher Wyss & Co., in a paper read before the Zurich Society of Engineers and Architects, stated that the Cussett Power Co., on the Jonage Canal at Lyons, charges £18 per H.P. per annum for power, while the average rate in Switzerland is only £6 per H.P. per annum.

At Niagara the rates charged to ordinary consumers by the Cataract Power and Conduit Co. vary from :—

1 penny	per unit	for	1,000	units	per month or less.	
·75	"	"	1,000	to	2,000	units per month.
·60	"	"	2,000	to	3,000	"
·50	"	"	3,000	to	5,000	"
·40	"	"	5,000	to	10,000	"
·375	"	"	10,000	to	20,000	"
to ·32	"	"	80,000	to	200,000	"

According to Messrs. Dumout & Baignères* the cost of electrical energy for power purposes from water power stations in France and Switzerland varies from 1·05 pence per unit for small powers to ·63 pence per unit for large powers.

In Columbus, Georgia ; Columbia, South Carolina ; and Anderson, South Carolina, electrical energy for power purposes, from water power stations, is sold to consumers requiring 1,000 H.P. and over at 15 dollars (£3 2s. 6d.) per horse power year, delivered on the secondaries of the transformers, the transformers being furnished by the Power Company. This energy can be used under contract for 66 hours per week, or 3,432 hours per year. Assuming that full advantage could be taken of the supply of energy available, or in other words that the load factor is 100%, the cost of energy works out at ·218 pence per unit, which is an extremely low figure. It must be remembered, however, that in most manufacturing industries the average demand is considerably below the maximum, and that in such cases the price per unit actually used will be considerably increased.

FUEL.

I do not propose in dealing with this branch of the subject to trouble you with speculations regarding either the extent or duration of the world's supply of fuel, but bearing in mind the fact that the sources of fuel supply are not inexhaustible, and that each year greater inroads are made upon such supply, I think a short review of the progress that has been made in the direction of the economical production of power from fuel, together with a statement of the best results obtained at the present time, as far as I have been able to obtain them, may be useful as indicating, in the case of many existing plants, the direction in which work must be undertaken in order to obtain greater economy in working. In this connection I need hardly point out that much of our industrial prosperity in the past has been due to the apparently inexhaustible supply of cheap fuel with which this country has been so richly endowed. As the years

* Memoires de la Sociéte des Ingénieures Civils de France, Oct., 1897.

go on, however, and as greater and greater inroads are made upon our fuel supplies, we must expect, in the nature of things, that the cost of fuel will increase, and to meet this increased cost it is essential that greater attention be given to the economical use of the fuel than has been the case in the past, and one of the most gratifying features in connection with this branch of the subject is the large amount of attention that is now being given in several quarters to the scientific treatment of the problems involved in the combustion of fuel, and I think we are to be congratulated as a Society in having the subject brought before us early on in the Session by my friend Mr. J. B. C. Kershaw, F.I.C., who is to address us on the subject of "Fuel Economy from the Chemical Point of View," a subject which, I may remark, he has made peculiarly his own.

In this country the fuel most commonly used for the production of power is coal, which is either used directly in the boiler furnaces for the production of steam, or is converted into power gas for use in the gas engine. In addition to this, however, the use of mineral oil as a liquid fuel for steam raising and as a working agent in internal combustion engines has been attended with a considerable degree of success, and more particularly in the latter case where it has been extensively used for the supply of energy to small power consumers, where steam cannot be used on account of the complication of a boiler, and where the gas engine is inadvisable owing to the cost and complication of a producing plant and the absence of gasworks in the neighbourhood.

A further reserve of fuel, which, up to the present has hardly been touched in this country is peat, which, for years past has been used on the Continent and Canada for steam raising and metallurgical purposes. In Ireland alone there is one million acres of bog 10 feet to 30 feet deep, which some day will doubtless be utilised, and will, in all probability, prove as profitable an undertaking as it has done on the Continent.

Dealing first with the use of coal for the production of steam it may be pointed out that the better class coals do not differ much in absolute calorific value, and that used in boilers of very different types and proportions and with greatly varying rates of combustion, the results obtained, provided the proper conditions of combustion are secured, do not differ very widely. As an example of this I would draw attention to the following table which I have taken from Professor Unwin's "James Forrest" Lecture on the "Experimental Study of Heat Engines" (Proc. Inst. C.E., Vol. CXXII.).

Type	Ratio of Grate to Heating Surface	Coal per sq. foot of grate per hour lbs.	Evaporation from and at 212° F. per lb. of coal	Coal
Cornish	— : —	7·2	11·9	Welsh
Lancashire ...	1 : 36	22·9	11·2	Lancashire
Galloway ...	1 : 24	8·5	11·6	Anthracite
Portable	1 : 69	12·8	11·8	Welsh
Tabular	1 : 46	10·8	11·9	Anthracite
Babcock	1 : 38	8·9	11·8	"
Marine	1 : 34	22·4	12·9	Welsh
"	1 : 50	25·5	12·5	Lancashire
Thorneycroft ...	1 : 70	7·7	13·4	Welsh
"	1 : 61	18·6	12·5	"

To supplement the above table I would draw attention to some figures published by the late Mr. Bryan Donkin, who carried out a series of tests with different classes of coal in the same boiler, the conditions in all cases being the same. In this table it will be noticed that the results of the tests are compared on the basis of the cost of fuel required to evaporate 1,000 gallons of water :—

Kind of Fuel	Cost of fuel per ton	Water evaporated per lb. of fuel	Cost of fuel per 1,000 galls. evaporated
	s. d.		s. d.
Dust Coke	5 0	6lbs.	3 8
Dust Welsh Coal ...	10 0	8 "	5 3
Large Welsh Coal ...	22 0	9 "	10 11

These latter figures go far to show the great advantage to be derived from burning a cheap class of fuel, but against this greater economy in the fuel must be set the additional work entailed in stoking, due to the fact that more fuel will have to be fired into the furnace every hour in order to get the same duty out of the boiler that would be obtained with the better class fuel, and the additional capital outlay in many instances in order to provide for the increased draught required to burn the lower grade of fuel used to the best advantage. It appears, therefore, that while the use of low grade fuels may reduce the coal bill, depending on the difference of the ratio of the calorific value to the price of the fuel used, it will also cause an increase in the working expenses, depending on the increase in the amount of fuel used.

Dealing now with the utilisation of the steam in the steam engine, it is interesting to note that the improvement in the duty of the steam engine has been coincident with the carrying out and publication of the reports of systematic testing of such engines. In the early days of the steam engine, Watt found the mining industry in Cornwall on the verge of extinction, owing to the excessive cost of working due to the high cost of coal and the inefficient working of the Newcomen engine. By agreement with the miners, tests were made, and the standard duty of the Newcomen engine fixed at 7,037,000 foot pounds per bushel (94 pounds) of coal, equivalent to (say) 26·6 pounds of coal per I.H.P. hour. Watt with his engines increased the duty to 20,000,000 foot pounds per bushel of coal, equal to (say) 9·3 pounds of coal per I.H.P. hour. Following Watt, whose connection with Cornwall ceased in the year 1800, Captain Joel Lean and his sons started again the system of duty trials and published reports of the results obtained, which had a very stimulating effect on the engineers of that day, for we find that while Watt, in 1800, obtained a duty of 20,000,000 foot pounds per bushel of coal, in 1815 the duty obtained, according to Captain Lean, had increased to 52,300,000; in 1827 to 67,000,000; in 1834 to 98,000,000, and in 1840 to 107,000,000 foot pounds per bushel of coal, equivalent to (say) 1·7 pounds of coal per I.H.P. hour, a result which even at the present day would be considered good, but which, considering the low pressures used—only some 36 to 45 pounds per square inch—speaks volumes for the Cornish pumping engine and its cycle.

Following Captain Lean, Isherwood, in America; Hirn & Hallauer, in Alsace; and Mair Rumley, Willans and Bryan Donkin in this country have all by their investigations and systematic experiments assisted in elucidating the apparent discrepancies between theory and practice, and in placing the theory of the steam engine on a rational basis.

It is not within the scope of an address such as this to describe in detail the various stages in the development of the theory of the steam engine, but it may be pointed out that while Watt patented expansive working, and while considerable economy resulted from the use of high ratios of expansion in the Cornish type engine, where the peculiar conditions of working were so favourable to high ratios of expansion, its application to the Watt rotative engine resulted in a duty of less than half that obtained in the Cornish engine. The discovery of the prejudicial effect of high ratios of expansion carried out in a single cylinder, with its consequent high temperature range, in causing large

initial condensation, and corresponding waste of steam, gave the key to the puzzle which had for so long confronted engineers, and pointed out the direction in which further economics in the utilisation of steam in the engine could be effected, and the scientific principles upon which, by the use of two, three or more stages of expansion, the difficulties encountered in the adoption of high ratios of expansion could be overcome. In recent years, there has been a revival in the use of superheating, which, in the light of our more intimate knowledge of the behaviour of the steam in the cylinder, and the advance that has been made in the production of suitable lubricants and packings, bids fair to have a great influence in further increasing the duty of the steam in the engine. I shall, however, have more to say on this point presently.

Attention has already been drawn to the fact that Watt fully understood the principles of expansive working, but it was Trevethick, Sims, and others who first perceived that increased expansion, and consequently greater economy, might result from the use of higher pressures.

As an illustration of the progress that has been made in the adoption of higher pressures, attention may be drawn to the fact that from an effective boiler pressure of about 5 pounds per square inch in 1800, the steam pressure has steadily increased, to (say) 50 to 60 pounds per square inch in 1872; 75 to 80 pounds per square inch in 1881; 150 to 160 pounds per square inch in 1891, and 200 to 220 pounds per square inch at the present time.

Referring now to the results obtained with the ordinary reciprocating steam engine, Mr. C. D. Gray, in a paper published in the Journal of the Franklin Institute in 1901, gives the following data as the average of the results of 250 engine tests:—

	Slide valve. Lbs. steam per I.H.P. Hour	Corliss. Lbs. steam per I.H.P. Hour
Simple Non-condensing	33·8	29·0
Compound Non-condensing	26·2	24·0
Simple Condensing	23·1	22·6
Compound Condensing	20·6	17·7
Triple Condensing	17·0	14·2
Large Pumping Engine, Simple	19·9	
" " " Compound ...	15·3	
" " " Simple	12·3	

As illustrating the best work that has been done, the following table is of interest :—

Type of Engine	I.H.P.	Boiler Pressure Lbs. per square inch	Piston Speed feet per minute	Steam per I.H.P. hour Lbs.
SIMPLE—				
Sulzer	284	87	372	18·4
Corliss	137	62	—	17·5
SIMPLE SUPERHEATING—				
Schmidt	18	135	350	17·8
Field	136	113	490	18·6
COMPOUND—				
Dujardin	548	90	570	13·46
Sulzer	247	85	493	13·35
Wheelock	590	160	612	12·84
Leavitt	643	135	371	12·16
Bollinckx	305	91	479	12·19
Van der Kerchove ...	167	130	718	11·64
COMPOUND SUPERHEATING—				
Schmidt	76	180	380	10·17
Schmidt	312	141	650	9·4
Van der Kerchove ...	215	130	718	8·86
TRIPLE—				
Willans	30	170	384	12·74
Sulzer	615	141	516	11·85
Alliss	574	120	203	11·68

It will be noticed from the above table that the results obtained from the compound engine using superheated steam are considerably lower than those obtained from the triple expansion engine using saturated steam. This is due to the fact that the behaviour of the superheated steam in the cylinder approaches that of a perfect gas, and that so long as it remains in that condition, its efficiency from the thermo-dynamic point of view is independent of the number of stages into which the expansion is divided. Of course the advantage obtained depends largely upon the type of engine and the degree of superheat adopted. With highly superheated steam, again, it does not appear to be necessary to use very high boiler pressures, 160 pounds per square inch being about the best modern practice. In the Schmidt system, in order to obtain the full benefit of superheating, the temperature of the steam is raised to about 700° Fahrenheit, and the steam taken first to the jacket of the intermediate receiver, where it gives a portion of its heat to the steam entering the low pressure cylinder, and from there it passes to the high pressure cylinder with a temperature of from 500° to 550° Fahrenheit, which appears to be a good working limit.

In the second Schmidt test referred to in the table, the temperature of the steam at the superheater was nearly 800° Fahrenheit, at entering the intermediate receiver it was about 750° Fahrenheit, and at the H.P. cylinder valve chest it was 580° Fahrenheit.

With Corliss engines, Messrs. Hick Hargraves claim to have used superheated steam with a temperature of 750° Fahrenheit at the superheater, and about 700° Fahrenheit at the engine, with engines of 1,000 I.H.P., with satisfactory results, but I do not think they recommend temperatures above 550° Fahrenheit at the engine, except in very exceptional cases.

In connection with this subject Mr. R. Lenke, in a paper read at the International Engineering Congress at Glasgow, in 1901, gives some interesting figures regarding the steam consumption of modern engines working under good conditions and using superheated steam, from which the following data is taken :—

	With Saturated Steam. Lbs. per I.H.P. hour	With Superheated Steam Lbs. per I.H.P. hour
Single Cylinder Condensing Steam Pressure, 90 to 100 lbs. per sq. inch	19 to 25	13½ to 15
Single Cylinder Non-condensing ...	—	15 to 18
Compound Non-condensing	—	14 to 16
Compound Condensing Steam Pressure 140 lbs. per square inch	—	Not exceeding 10

STEAM TURBINES.

In the reciprocating steam engine, work is done by means of the static force of the steam acting behind a piston, while in the steam turbine the work is developed by the kinetic energy of the particles of steam, which are given a high velocity by reason of the steam expanding from a higher to a lower pressure.

In the case of the De Laval turbine, which may be described as an impulse wheel, and is the invention of Mr. Carl de Laval, of Sweden, the total power of the steam is devoted to the production of velocity in an expanding nozzle, which directs the jet of steam upon suitable formed buckets attached to the periphery of a revolving wheel, the outer edge of which is shrouded by a steel ring which prevents the centrifugal escape of the steam. This produces very high rotative speed which, in the smaller sizes, is as high as 30,000 revolutions per minute, and in the larger sizes about 10,000 revolutions per minute, the peripheral speed usually adopted varying from 600 to 1,200 feet per second. It will be noted that the rotative speeds are

extremely high, and special reduction gearing is therefore necessary to enable the turbine to be used for dynamo driving and other similar work, the reduction gearing consisting of a pair of helical spur gears with an angle of helix of 45°, which effects a 10 to 1 reduction.

In both water and steam turbines the theoretical condition of maximum economy exists when the velocity of the bucket upon which the jet impinges is one-half that of the impinging jet, and as with 150 pounds steam pressure, and 26-inch vacuum, the steam leaving the nozzle would have a velocity of about 3,800 feet per second, assuming the whole of the energy of the steam to have been converted into velocity, it will be seen that this wheel falls considerably short of the theoretically economical speed.

In the Parsons turbine, which is the one most extensively used at the present time in this country, and which was invented by the Hon. Charles A. Parsons, the steam is carried in an axial instead of a tangential direction. In this turbine the body or shell contains a series of revolving discs from the surface of which the turbine blades project, the blades being arranged on each disc in a series of concentric rings, while in the space between these rings, and carried by annular discs fixed to the body or shell of the turbine, the fixed guide plates stand. It will thus be noticed that each revolving disc, with its neighbouring fixed disc, forms a series of outward-flow turbines, the steam entering the series inside the smallest ring of blades and escaping at the circumference into a channel which conducts it to the inside of the next series of rings. It may further be pointed out that by increasing the diameter of the various discs or groups of discs as the steam expands, the total expansion may be divided into stages, and any required degree of expansion obtained. In this turbine the steam in expanding through the fixed or guide disc converts its energy into velocity and impinges upon the blades in the moving disc. It then performs a second expansion in expanding through this moving disc, again converting its energy into velocity, but this time the energy of efflux reacts upon the blades from which the steam issues. This cycle is then repeated in each disc until the exhaust pressure is reached, the total available head being thus divided between the series of discs forming the turbine, and in this way the peripheral speed of the moving discs is kept within reasonable limits without violating the conditions of maximum economy before referred to.

In the Curtis turbine, which is the invention of Mr. C. J. Curtis, of New York, and which is at the present time receiving a considerable

amount of attention both in this country and in the United States, some of the leading features of both the De Laval and the Parsons turbine are retained, but new ideas are introduced which, it is claimed, tend to reduce the speed and simplify the construction. In this turbine velocity is imparted to the steam in a series of expanding nozzles, as in the De Laval turbine, so designed that the power of the steam between the pressure limits used is devoted to the production of velocity. After leaving these nozzles the steam passes through a series of moving and fixed discs, similar to those used in the Parsons turbine, where the velocity acquired in the nozzles is fractionally abstracted and largely given up to the moving element. This process of expansion in nozzles, and subsequent abstraction of velocity by successive impacts with blades carried on the moving discs, is generally repeated two or more times, each combination of nozzles being known as a stage, the number of stages, and the number of moving discs in a stage, being governed largely by the degree of expansion and the peripheral velocity desired or practicable.

Generally speaking, the lower the peripheral speed the greater the number of discs, and the larger number of moving discs per stage.

There are, of course, a number of other turbines on the market, but as the foregoing are the only ones concerning which I have been able to obtain any working data, I have thought it better to confine my remarks to them.

In dealing with the reciprocating steam engine, attention was drawn to the losses due to initial condensation, caused by the cylinder walls being alternately exposed to the action of steam having a temperature range between that of the boiler and the condenser. In the turbine, however, the flow is all in one direction, and there is consequently no periodic variation and no loss from this cause.

Although at first sight it would appear that little gain in economy would result from the use of superheated steam, the results of careful tests show a decided gain. Thus, Professor Thurston, experimenting with a De Laval turbine, obtained an increased economy of 1 per cent. for every 30° Fah. of superheat, which he attributed almost entirely to the reduction in skin friction.

Mr. Gerald Storey, in tests made with the Parsons turbine, has observed that a small degree of superheat gave an increased economy of about 5 or 6 per cent.; 50° Fah. 8 per cent., and 100° Fah. 12 per cent.; while Mr. Francis Hodgkinson in a paper read before the Engineers' Society of Western Pennsylvania in November, 1900, claims an increased economy of 20 per cent. for a superheat of from

60° to 70° Fah. The turbine, however, is well adapted for the use of superheated steam, as there are no internal rubbing surfaces and no packing. It follows, therefore, that no internal lubrication is required, and this enables surface condensers to be used, and the condensed water utilised for boiler feed without the danger of grease finding its way into the boilers.

Prior to 1890 the Parsons turbines were all of the non-condensing type, and of comparatively small size. In the intervening 12 or 13 years, however, great progress has been made, and to-day steam turbines directly coupled to electric railway generators of 5,500 K.W. capacity are now being made by the British Westinghouse Company for the District Railway Company, and Curtis turbines of 5,000 K.W. capacity have been made by the General Electric Co. of America.

The following table, which gives details of some of the published tests of steam turbines, is, I think, a very fair illustration of what may be expected from steam turbines under the conditions stated :—

Type	H.P.	Steam Pressure Lbs. per square inch	Steam Temperature at		Vacuum	Steam Consumption lbs. per	
			Super-heater	Throttle Valve		B.H.P. hour	K.W. hour
Laval ...	100	176·3	509° F.	374° F.	24·8	18·1	—
" ...	100	—	—	468° F.	25·8	15·4	—
" ...	307·8	192·0	69° F. Superheat.		—	13·92	—
rsons ...	138·3 KW	150·8	90° F.	"	27·05	—	22·8
" ...	204·4 "	134·0	76° F.	"	27·4	—	20·8
" ...	*303·2 "	158·0	None.		26·25	—	23·15
" ...	359·5 "	150·0	71·3° F. Superheat.		27·7	—	20·64
" ...	312·1 "	150·0	53·3° F.	"	27·63	—	20·06
" ...	1442·0 "	196·0	27° F.	"	27·	—	18·0
" ...	251·5 "	144·0	None.		N.C.	—	37·8
" ...	308·6 "	97·7	"		N.C.	—	41·3
" ...	*296·6 "	161·0	"		N.C.	—	34·3
rtis ...	600·0 "	140·0	"		28·5	—	19·15
" ...	600·0 "	140·0	150° F. Superheat.		28·5	—	16·75

* The results marked thus are interesting as illustrating the effect on the steam usumption of running condensing and non-condensing, the tests being carried out the same turbine. The figures for the Curtis turbine, it may be remarked, are ken from a pamphlet published by the General Electric Company of America.

INTERNAL COMBUSTION ENGINES.

One of the most interesting phases of the power problem is the vast possibilities possessed by the modern internal combustion engine. Up to the year 1888, 40 H.P. appears to have been the largest size gas engine put upon the market in this country, and in 1889 the 100 H.P. single cylinder gas engine exhibited at the Paris Exhibition was considered to be of colossal size. Up to this time, however, all gas engines were designed for use with town's gas, which, for any but the smaller sizes proved to be too expensive in fuel costs to enable them to compete with the steam engine. The next step in advance was the introduction of the Dowson gas producer, in which small anthracite coal or coke is put into a brick-lined producer and thoroughly ignited, after which steam and air are blown in, in fixed proportions, and the resultant gases cooled prior to delivery to the gas holder. The latest phase in the development of gas producers is, however, the Mond and Duff producers, which are adapted for the use of cheap bituminous fuel and the recovery of ammonia. In the Mond producer, which has been fully described in a paper read before the Institution of Mechanical Engineers in 1900, by Mr. H. A. Humphreys, common bituminous slack is fed into hoppers, and then descends in charges of from 5 to 10 cwt., depending upon the size of the producer, into the producer bell; the first heating of the slack distils off the hydro-carbons, &c., which pass down through a hot zone, where the tar is broken up. In the body of the producer is an air blast saturated with steam at about 185° Fah., and superheated before coming into contact with the fuel; the quantity of steam introduced with the blast amounting to $2\frac{1}{2}$ tons per ton of fuel gasified; the large amount of steam used being introduced to keep down the temperature and prevent the destruction of the ammonia. About half a ton of this steam is decomposed in the producer, yielding thereby a large amount of free hydrogen; and of the undecomposed steam nearly one ton per ton of fuel gasified is recovered and returned to the producer. In plants where the ammonia is not recovered the quantity of steam necessary for the good working of the producer is about the same as in other producers, and amounts to about one ton for every ton of fuel gasified.

In the ammonia recovery plant the gases and undecomposed steam pass through a tubular regenerator in the opposite direction to the incoming blast, thus causing an exchange of heat to take place, the blast being further heated by passing down the annular space between

the two shells of the producer on its way to the fire grate. The whole products from the producer are then passed through a washer, where, by means of a spray, they are cooled down to some 194° Fahrenheit, and then to a lead-lined tower filled with tiles, where they meet a down-coming current of acid liquor, containing sulphate of ammonia, with a small amount of $H_2 SO_4$, and in this tower the ammonia gas is recovered. The gases then pass to a gas cooling tower, where they meet a current of cold water and become fit for use in the engine.

A further advance in the economical production of power by internal combustion engines was made in the year 1894, when Mr. B. H. Thwaites proposed the utilisation of the waste gases from blast furnaces to drive gas engines, the scheme being carried into effect in the following year, when an engine developing about 15 H.P. was put down at the Glasgow Iron and Steel Works, at Wishaw. The principal difficulty experienced in utilising these gases lies in the separation of the minute particles of floating ash and cinder from the hot gases escaping from the furnaces. This difficulty has, however, been satisfactorily met, and at the present time gas engines of 2,000 H.P. and upwards are at work upon the Continent using blast-furnace gases, and a number of engines of 600 H.P. and upwards are in use in this country. In this matter the Continental engineers have taken the lead, but it is gratifying to note that there has recently been a decided waking up of ironmasters in this country to the importance of the waste furnace gases as an economical source of power, and indications are not wanting that a very considerable amount of work will be done during the next few years in this branch of engineering.

In the year 1895, a very important paper was read before this Society by Dr. C. A. Kohn and Professor F. G. Bailey, (Vol. XVI) on the utilisation of coke oven gas for the economical production of power in gas engines, but up to the present very little has been done in this direction, although a plant of this description, consisting of three 145 H.P. gas engines, has been running at Streckau, in North Germany, since May, 1898.

In certain parts of the United States and Russia, gas, produced by the heat of the earth and the slow combustion of chemical decomposition acting upon the masses of decayed vegetation of bygone ages, frequently escapes through fissures in the ground into the atmosphere. This gas, generally known as natural gas, was formerly allowed to escape to waste, but is now partially utilised for lighting, heating and power purposes in several towns in the United States, being of excellent quality for such purposes. The application of this

gas is, however, of purely local interest, and I do not purpose considering it in further detail.

For the purpose of comparison the average thermal values of the different descriptions of gases used for power purposes is of interest:

Natural Gas ...	... 1,033	British	Thermal	Units per cubic foot.
Coal Gas (mean)	... 680	"	"	"
Coke Oven Gas	... 540	"	"	"
Water Gas Carburetted	651	"	"	"
Water Gas Uncarburetted	319	"	"	"
Producer Gas	... 145	"	"	"
Blast Furnace Gas	... 110	"	"	"

Since 1882 the efficiency of the gas engine has been increased from 15·2 per cent. to 33·65 or 37·66 per cent. per I.H.P., depending upon whether the higher or lower thermal value of the gas is used. This increased efficiency is due in large measure to the adoption of higher compression, which has increased from about 38 pounds per square inch in 1882, to about 147 pounds per square inch at the present time; to the use of the scavenging action to clear the cylinder of the hot products of combustion, and, by cooling down its walls, to prepare it for the incoming charge of gas and air; and in the larger sizes to the adoption of water-cooled pistons, piston rods and valves.

In the Diesel engine, which is one of the most interesting developments in internal combustion engines, air is compressed in a water jacketed cylinder to a pressure of about 500 pounds per square inch, under which compression the air becomes sufficiently hot to ignite the charge of oil, which is then injected or sprayed into the combustion chamber, the amount of oil so injected being controlled by the governor. The working stroke is then made, during the first portion of which the combustion of the fuel is carried on at constant pressure, and the engine completes its cycle of operation by exhausting the products of combustion and taking in the fresh charge of air as in the ordinary gas engine.

The fuel used in the Diesel engine is crude petroleum, having a specific gravity of 0·922, and a calorific value of about 19,150 British Thermal Units per pound. There is, however, no reason why gas or coal dust should not be used. From the average of a number of tests the consumption of oil appears to vary from ·45 to ·5 pounds per B.H.P. hour.

The thermal efficiency of this engine is high, being 36·3 per cent. for the 35 B.H.P. size, 39·9 per cent. for the 80 B.H.P. size, and

40 per cent. for the 160 B.H.P. size; the efficiency in all cases being calculated on the nett indicated horse power.

COST OF PRODUCTION OF POWER FROM FUEL.

A very considerable amount of data has been published, both in this country and in the United States, giving particulars of the cost of production of power, among the most interesting of which are the details of cost per H.P. of steam power plants tested by Mr. H. A. Foster* in the United States, the plants so tested including:—

2 Electric Light Stations.
1 Grain Elevator.
3 Water Works Pumping Engines.
2 Flour Mills.
6 Cotton Mills.
4 Newspaper and Printing Offices.
4 Other Works.

Taking an average of 3,080 working hours per annum, Mr. Foster estimated the average working cost per H.P. hour to be about ·412 pence, the costs, including fuel, wages, stores, repairs, water, incidentals (including lighting and removal of ashes), fixed charges, interest and depreciation, insurance and taxes. Where the cost of an item was found to depend upon the locality it was reduced to a certain standard of comparison. Other American authorities, notably Mr. C. E. Emery, have devoted a considerable amount of attention to this subject, and the following comparison of their conclusions, with the results obtained by Mr. Foster, will not be without interest, the estimated costs being based on the use of large compound condensing engines.

		Cost per H.P. hour in pence.
Emery—for 3,080 hours per annum	... ...	·392
Do. " 7,090 " "	... ...	·3085
Do. " 3,080 " "	... ...	·428
Webber " 650 H.P. for 3,080 hours per annum	...	·360
Do. " 1,050 " " "	...	·323
Hale " 2,985 hours per annum	... ...	·2785
Main " 3,080 " "	... ...	·3185
Foster (average of 23 tests) for 3,080 hours per annum		·412
Average cost per H.P. hour in pence	...	·3525

* Proc. Inst. C.E., Vol. CXXXIII, page 477.

Mr. C. D. Gray, whose paper in the Journal of the Franklin Institute has already been referred to, found the cost of steam power to vary as follows :—

Standing Charges from	·045 to ·37	pence per H.P. hour.
Running Charges from	·115 to 1·22	" " " "
Total costs from	·155 to 1·45	" " " "
Average costs ...	·475	pence per H.P. hour.

In the discussion on a recent paper read by Mr. A. D. Williamson before the Members of the Institution of Electrical Engineers,* Mr. H. A. Maver gave the following figures of costs, taken from different parts of the country, and over widely different industries, which, I think, are amongst the most interesting that have yet been published : and in which, for the purpose of comparison, the price of coal has been corrected to 100 pence per ton, or ·045 pence per pound. It will be noticed, however, that nothing has been included in these costs for water, repairs and maintenance, interest and depreciation, or rates and taxes, so that although extremely valuable as examples of running costs they are not comparable with the American costs I have just referred to. In the last column, in order to compare the results with the generation cost in electricity works, the costs have been reduced to pence per B.O.T. unit, by taking 600 watts as equal to one I.H.P. (See Table, page 21.)

Dealing now with the advances made in reducing the cost of production of power in electricity supply works, it may be pointed out that in 1894 Mr. (now Colonel) R. E. Crompton prophesied that the day would come when with an output of 5,000,000 Board of Trade Units per annum the cost of production and distribution, in places where best coal costs 20s. per ton, would work out :—

Fuel	·27	pence per unit.
Oil, Waste and Water	·03	" "
Repairs and Maintenance	·10	" "
Works costs ...	·75	" "
Rent, Rates and Taxes and Management, including Engineer's Superintendence	·57	" "
	1·32	" "

* Journal Inst. E.E., Vol. XXXII., August, 1893.

Class of Factory	Hours per Annum	I.H.P. hours. Thousands	Coal per I.H.P. hour in Lbs.	Coal per I.H.P. hour in Pence	Wages per I.H.P. hour in Pence	Oil and Stores per I.H.P. hour in Pence	Total costs per I.H.P. hour in Pence	Cost in Pence per B.O.T. unit
Weaving	2,888	2,550	2·5	·112	·013	·011	·136	·227
Spinning	2,800	2,350	2·25	·1	·02	·012	·132	·220
Do.	2,850	640	2·72	·122	·04	·013	·175	·292
Flour	5,500	1,920	2·68	·12	·036	·013	·169	·282
Engineering	2,700	360	4·8	·214	·068	·013	·295	·492
Corn Mills	6,000	2,160	2·0	·09	·043	·012	·145	·242
Thread	2,800	15,300	3·5	·156	·025	·01	·191	·320
Tweed	2,900	1,000	6·0	·27	·073	·014	·357	·595
Paper	7,312	5,120	5·0	·222	·025	·01	·257	·43
Do.	7,200	2,400	5·65	·207	·04	·015	·262	·437
Chemical	6,500	2,400	5·0	·222	·02	·002	·244	·407
Paper	6,700	4,690	3·85	·172	·032	·01	·214	·357
Engineering	2,808	200	27·85	1·25	·18	·03	1·46	2·43
Do.	3,100	540	18·5	·825	·09	·03	·945	1·575
Sugar Refining... ...	6,900	320	14·0	·625	·16	·012	·797	1·33
Paper	7,000	6,300	4·9	·22	·052	·011	·283	·472
Shipbuilding	2,650	530	15·4	·69	·154	·08	·924	1·54
Electrical Engineering	—	—	—	—	—	—	·503	·838
Chemical	—	—	—	—	—	—	·18	·3

In 1896, however, the Edinburgh Electricity Works, then only in its second year of operation, improved upon Colonel Crompton's ideal costs, as with an output of 1,721,557 units per annum, the works costs were but ·63 pence per unit, and the total costs 1·13 pence per unit. In this case, however, the price of coal would be below the price upon which Mr. Crompton based his figures, but allowing that the Edinburgh coal cost but 8s. per ton, the comparative costs are in favour of Edinburgh.

In 1898, Mr. Hammond, with Colonel Crompton's figures before him, ventured on a prophesy as to the reduction of costs in works situated in an industrial centre, and stated that, in his opinion, when the Leeds output reached 5,000,000 units per annum, the cost of production and distribution would work out as follows:—

Fuel	·20	pence	per unit.
Oil, Waste and Stores	·03	"	"
Wages	·17	"	"
Repairs and Maintenance	·10	"	"
Works costs ...	·50	"	"
Rates and Taxes	·03	"	"
Management Expenses, including Engineer's Superintendence ...	·22	"	"
Total costs ...	·75	"	"

Last year the total costs at Bradford fell to Mr. Hammond's estimate, while those at Bolton, Bootle and Leeds—with the exception of Leeds, all combined lighting and traction stations—approached very closely to them, the figures being:—

	Bradford	Bolton	Bootle	Leeds
Output in B.O.T. units ...	9,124,223	3,802,598	1,619,129	4,448,650
Fuel, Pence per Unit	·26	·35	·41	·28
Oil, Waste and Stores "	·05	·03	·06	·03
Wages ... ... "	·08	·15	·15	·17
Repairs and Maintenance .. "	·13	·10	·11	·14
Works Costs ... "	·52	·66	·70	·62
Rates and Taxes ... "	·11	·07	·05	·08
Management ... "	·12	·08	·13	·19
Total cost per unit in pence...	·75	·81	·88	·89

In order that one may appreciate the advance that has been made in reducing the costs of production, it may be pointed out that in

1894, the year Colonel Crompton made his forecast, the works costs in Manchester, which held the record for that year, were 1·49 pence.

For purely traction purposes the following are the lowest recorded costs, but it must be remembered that in the case of traction stations the figures only represent the cost of the energy delivered to the switch-board omnibus-bars, and do not allow for any losses in distribution :—

	Dublin	Glasgow	Leeds	Huddersfield
Output in B.O.T. Units	7,452,862	10,527,489	8,120,740	2,068,690
Fuel, Pence per unit	·30	·19	·20	·14
Oil, Waste and Stores " "	·03	·05	·04	—
Wages and Salaries " "	·14	·22	·09	·13
Repairs and Maintenance "	·15	·14	·11	·09
Works Costs, Pence per unit	·62	·60	·44	·36

The only power scheme which has been in operation for over 12 months is that of the Newcastle-upon-Tyne Electric Supply Co., where the costs, delivered at the switch-board omnibus-bars of the Neptune Bank Power Station, for the year ending 31st December, 1902, were as follows :—

Coal	·155	pence	per unit.
Water, Oil and Station Stores ...	·027	"	"
Shift Wages	·078	"	"
Engineers and Assistants ...	·031	"	"
Repairs, Wages and Material ...	·033	"	"
Total station charges	·324	"	"

N.B.—The above are exclusive of General Expenses, Rents, Rates and Taxes.

The lowest price at which electrical energy is sold in bulk is £3 10s. per annum per K.W. demanded, plus 0·35 pence per unit, at which price the Newcastle Electric Supply Company are giving a supply to the County of Durham Electric Supply Company. This is equivalent to 2·65 pence per unit for the first hour's supply per day at the maximum rate of demand, and ·35 pence per unit for the subsequent supply.

For smaller quantities, the Trafford Park Power and Light Company's supply at the rate of $\frac{7}{8}$ths of a penny per unit to certain Companies on the Trafford Park Estate, is, I think, a record.

Turning now for a moment to gas driven electrical supply works, it may be remarked that until recently the experience with gas driven

stations had not been very satisfactory. At Walthamstow, however, where Dowson gas producers in conjunction with Westinghouse engines and generators are used, the results of the first year's operations are very encouraging, the costs in pence per unit being as follows :—

Output. B.O.T. Units	Fuel	Oil, Waste and Stores	Wages	Repairs and Maintenance	Works Costs	Rent, Rates and Taxes	Management	Total Costs
542,423	·42	·23	·41	·12	1·18	·05	·31	1·54

In spite of the high price paid for the Anthracite coal used in the producers, the costs at Walthamstow compare very favourably with those in other towns of a similar size, where steam is used as a motive power, and where the demand is purely for lighting and power purposes.

Having thus briefly dealt with the costs of production in undertakings working under statutory powers, it will, I think, be interesting for purposes of comparison to see what is being done in private undertakings.

Amongst the most interesting figures of cost of production in private plants, the costs at the Sheffield works of Messrs. Vickers, Son and Maxim, Limited, may be instanced.*

	North Power House	South Power House
Capacity in Kilowatts	640	1325
Annual Output, B.O.T. Units	2,106,340	2,610,620
Cost of Fuel per Ton	9/8½	7/2½
Coal per Unit in pence	·313	·255
Water per Unit in pence	·046	·101
Stores " " " "	·017	·016
Repairs " " " "	·101	·081
Works costs	·579 pence	·469 pence
Taxes, pence per unit	·027 "	·026 "
Share of Works Railway carting Coal and Ashes, Boiler Insurance, Employees' Compensation, &c.	·004 "	·004 "
Interest and Depreciation	·106 "	·177 "
Total costs per unit ...	·716 pence	·675 pence

* Mr. A. D. Williamson on "Application of Electricity in Engineering and Shipbuilding Works."—Journal Inst. E.E., Vol. XXXII., page 931.

In another case, that of an engineering works with a mean indicated horse power of 773, the costs for a week's test of 139½ hours, and an output of 60,403 B.O.T. units, worked out as follows :—

Coal at 11s. 6d. per ton ...	·187	pence	per unit.
Water at 3½d. per 1,000 gallons	·009	"	"
Stores	·010	"	"
Wages	·066	"	"
Repairs	·016	"	"
Superintendence	·012	"	"
Interest and Depreciation ...	·099	"	"
Total cost ...	·399	"	"

At Messrs. Cadbury's works, Birmingham, the cost with a 500 H.P. five-ton Mond producer (without recovery plant) and two 150 K.W. gas driven generators were, for the week ending 24th January, 1903, as follows :—

Producer Coal at 10s. 11d. per ton	·125	pence	per unit.
Coal for raising steam for producer	·013	"	"
Oil	·055	"	"
Gas Plant, labour	·08	"	"
Generating Station labour ...	·071	"	"
Works cost ...	·344	"	"

As a final example I would instance Mr. H. A. Humphrey's estimate of the "costs" to be obtained from a 20,000 E.H.P. Gas Plant with sulphate of ammonia recovery, and with a load factor of 33-1/3 per cent. They are as follows :—

Fuel at 8s. per ton, after allowing for sulphate of ammonia recovered	·042	pence	per unit.
Oil, Waste and Stores	·030	"	"
Labour and Attendance ...	·068	"	"
Repairs and Maintenance ...	·077	"	"
Works cost ...	·217	"	"

CONCLUSION.

I have, in addressing you this evening, endeavoured, in a very incomplete manner, I fear, to deal with the question of the economical production of power. The subject, however, is a very large one, and

in the limits of an address such as this, many important points have necessarily to be left untouched.

At the present time, both the steam turbine and the gas engine are coming prominently into favour, and great developments in their application may be expected during the next few years. As regards the future, I believe much will be done in the way of utilising the heat now going to waste in many of our manufacturing processes, and as a striking illustration of the possibilities in this direction, I would instance the utilisation of the waste gases from blast furnaces, where, taking the figures given by the late Mr. Bryan Donkin for the world's output of iron from blast furnaces in 1899, as 40,000,000 tons, and assuming a consumption of one ton of coke per ton of pig iron, with a production of 170,000 cubic feet of gas, the total indicated horse power available from this source alone would be 6,400,000.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

SECOND MEETING—18TH NOVEMBER, 1903.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. GEORGE BALFOUR, DOUGLAS J. CALLOW, JOHN A. HIRST, LOUIS J. HUNT, W. D. KIRKPATRICK, E. W. MARCHANT, H. S. MEYER, C. MAXWELL STEVENSON, and DANIEL WILLIAMS, as *Members;* Mr. G. J. JACKSON, as an *Associate Member;* Messrs. L. R. S. C. BLAKE and T. PERCIVAL LLOYD, as *Associates;* and Messrs. J. BRUCE GALLOWAY, ERIC D. S. SHELMERDINE, and H. BERNARD WARD, as *Students.*

FUEL ECONOMY FROM THE CHEMICAL POINT OF VIEW.

BY JOHN B. C. KERSHAW, F.I.C., F.S.S.

IN venturing to offer to the Liverpool Engineering Society a Paper upon the subject of "Fuel Economy from the Chemical Point of View," the author has not overlooked the fact that an excellent paper upon the "Economy of Fuel in Factories" was read before the Society in February, 1902, by Mr. P. M. Pritchard, and that a most interesting and valuable discussion followed on that occasion. Mr. Pritchard's paper, however, dealt with the subject more from the Engineering than from the Chemical standpoint, and in the author's opinion the question of *Fuel Economy* is sufficiently wide, and the financial interests involved in it are sufficiently great, to give interest and value to a further study of the subject from the chemist's point of view. The present paper may therefore be regarded as complementary to the earlier one by Mr. Pritchard, and a repetition of the facts, figures, or arguments contained in that paper will, as far as possible, be avoided. In the paper to which reference has been made, Mr. Pritchard

dealt especially with factory and engineering works, installations of steam-power. The author, when referring to actual practice, will draw his illustrations chiefly from the large and well-equipped steam-raising plants to be found in connection with the modern Electric Lighting and Power Stations. As the present session of this society is presided over by a distinguished Electrical Engineer, and as the Papers presented during the session will be chiefly electrical in character, the paper will thus fall into line with those that follow it, and will perhaps prove of value to the Electrical Engineers who are Members or Associates of this Society.

The past attitude of the average works engineer towards the subject of Fuel Economy, as Mr. Pritchard pointed out in the introduction to his 1902 paper, has been less progressive than in other directions. It is doubtful if he has even yet awakened to a realization of the fact that there is much greater scope for economy in the boiler house than in the dynamo or engine rooms. The following extracts from the editorial columns of recent issues of two leading technical journals, prove that Mr. Pritchard and the author of this paper are not alone in the opinion that much room for improvement exists :—

In the writer's experience of electrical installations, the engineering part of the works—boilers, chimneys, flues, fuels, engines, condensers, economisers and a hundred and one other details—demand more skill and knowledge than the electrical part of the plant, and amount to much more in value. And upon these details depends the success of a plant and its economy, much more than upon the question whether the dynamo has an efficiency of 90 or 94 per cent., and runs at 40 degrees or 50 degrees C. above atmospheric temperature. The electrical engineer who knows only the electrical science and art of the business is only half equipped.—*Electrical Review*, 3rd April, 1903.

There is strong ground for belief that the average evaporative efficiency of boiler plants in this country is much beneath the maximum possible, and that an improvement of from 15 per cent. to 30 per cent. would be obtained were greater attention given to the subject by the engineer in charge. Fuel forms the largest item of cost of production in power generation, and engineers would therefore be well advised to adopt a more scientific attitude in regard to the use of coal under their boilers. There is no mystery, and nothing supernatural about it ; only a little common sense is required, and a conviction on the part of steam users that they will gain more than they lose, by a regular appeal to the scientific expert for assistance and advice with regard to their steam plant.—*Engineering*, 17th April, 1903.

It is possibly true that engineers have not been more backward than other fuel users, in recognising the need for a scientific study of the question of fuel economy, and for the use of scientific, rather than rule-of-thumb methods, in the control of the combustion process. The author, therefore, is not disposed to blame them specially for

their attitude in this matter. It is simply an expression of the general neglect of science by manufacturers in the United Kingdom, that is now admitted by most thinking men, and that is certainly one of the *many* causes which have led to our present somewhat unsatisfactory position as a manufacturing country.

With these introductory remarks and extracts the author trusts that a majority of those present are in agreement, and in the following portions of his paper he will discuss the economies which, as a chemist, he believes to be possible in connection with the raising of steam in large engineering plants. The use of fuel for domestic purposes or for metallurgical work, is not within the scope of the paper.

For the purpose of the paper he will divide his subject into three sections, and will deal, Firstly, with *The Supplies of Fuel and Water;* Secondly, with *The Combustion of the Fuel in the Boiler Furnace;* and Thirdly, with *The Waste Gases from the combustion process.* Under each of these headings he will point out the defects of the present methods of examination and control, and will make suggestions which he considers would lead to great economies in actual practice.

I.—FUEL SUPPLY.

The chemist, when he regards the conditions under which the engineer in charge of a large generating plant, arranges his contracts for thousands of tons of fuel to be delivered over a period of some months, is struck by the absence of any effective means for checking the quality of the deliveries of the selected fuel. Fuel appears to be the only raw material the sale of which is conducted by what may fairly be called rule-of-thumb methods in place of scientifically exact tests.

Steam-raising trials are of course made, with sample waggons of various fuels, before the contract is signed, and the selection is based upon the results obtained in these trials. Here at the very basis of the system of selection there is wide scope for uncertainty and error. The comparative wetness or dryness of the fuel as it is discharged into the boiler-house — a physical condition which must vary enormously in such a climate as ours, with coal carried long distances in open waggons; the humidity and coldness of the atmosphere, and the direction of the wind (all causes which influence the pull of the chimney); the state of the boilers as regards scale; and finally—but not least—the skill and reliability of the fireman; are all factors which have great influence upon the results obtained in these "practical" steam-raising trials. The "reliability" of the fireman is perhaps the

most important, though many engineers do not recognise this. Even where mechanical stokers are employed, the fireman in charge has much influence over the results obtained. In these days of secret gifts and commissions to men in high social position, a small present of 10s. or £1 to a fireman, or £5 to the engineer of a boiler plant, is considered by many a very venial offence. But such a present, if accepted, would most certainly influence the results obtained in the practical trials of various fuels for the purpose of placing a large coal contract. Are not engineers a little too trustful of human nature in this matter; and would it not be advisable to have some counter-check upon the results of steam-raising trials of fuels under the boilers? The author then recommends—not that such practical trials should be dispensed with, but that a thoroughly reliable sample of the fuel used for each steam-raising test should be submitted to chemical and calorific examination; and that the results obtained in the trials under the boilers should be judged in the light of these laboratory results. If striking discrepancies should be revealed, the practical trials could be repeated with other men in charge, and these might in some cases prove that the author's suspicions of "palm-oil" having been dispensed by interested parties, were justified. (A quotation bearing on this point from the 1902 Memorandum prepared by Mr. Stromeyer for the Members of the Manchester Steam Users' Association is given in the Appendix.)

In Table I. of the Appendix to this Paper, the results of a large number of laboratory tests of various bituminous and anthracite fuels made by the author during the last eighteen months are given, and these prove the value of such examinations for practical purposes. Attention is especially directed to column 8, which contains the calorific value calculated by Goutel's formula from the results of the approximate analysis, and to column 10, which contains the calories obtained per unit of cost for the fuel as delivered in the bunkers. This last figure is obtained by dividing the calories, by the cost per ton in pence, and the results enable one to compare scientifically the relative value of fuels with two variable factors:—viz., price and heating power. The author recommends for practical purposes the "approximate" rather than the "elementary" analysis of fuels. The former gives the per cent. of moisture, coke, volatile matters, fixed carbon and ash. The latter yields the percentage of the various elements, which are contained in the fuel:—viz., oxygen, hydrogen, nitrogen and carbon. For the guidance of the boiler engineer it is much more useful to know that a fuel contains (say) 29 per cent. of

volatile hydrocarbons, 13 per cent. ash, and 58 per cent. fixed carbon, than to be informed that it contains 72 per cent. C, 4·8 per cent. H, 7·2 per cent. O, and ·71 per cent. N. Recently a formula has been published (see Appendix) which permits the calorific value to be calculated from the results obtained by this "approximate" analysis; and therefore one of the arguments for carrying out the troublesome and expensive elementary analysis of fuels, viz., that it enabled one to calculate with accuracy its calorific value, has lost weight.

In the author's opinion such approximate analysis of fuel ought always to be made in conjunction with practical steam-raising trials; and in the decision as to the choice of fuel, the laboratory results ought to have due weight. A further advantage of having the exact figures of the laboratory trials of the fuel for reference, is, that a check upon the deliveries of fuel during the time for which the contract is running can be easily kept. At weekly, fortnightly, or monthly intervals, reliable samples of the fuel should be taken and submitted to the approximate analysis, and laboratory calorimetric tests. Any variation in the quality of the fuel should at once be reported; and the fact that such examination of their deliveries at the boilers was being periodically made, would have undoubted effect upon the firm fulfilling the fuel contract, and upon the colliery managers. It is not generally recognised that one colliery often supplies five or six varieties and qualities of coal from the different seams worked, with ash contents varying from 6 per cent. up to 20 per cent. The author knows one such example in the St. Helens district. At times accidentally, and at times, possibly, intentionally, buyers may be provided with a fuel much inferior to that for which they had contracted. Unless the fireman complains, nothing is known or said about this deterioration; and as already pointed out the fireman may have some interest in keeping quiet. Coal-seams also become worked out in time, and such an incident may occur during the delivery of a contract. Hence the importance of instituting some scientific and systematic check upon the quality of the fuel deliveries. Such a check is offered by the laboratory examination of the fuel for all large steam-users.

It may be urged that periodic steam-raising trials are sufficient. Apart from the unreliability already referred to of the results obtained in such trials as guides to the quality of the fuel actually being delivered, there is the question of trouble and expense involved in conducting them. On the ground of expense alone, the laboratory examination of carefully taken samples is to be preferred.

The chemical examination of fuel is regularly carried out in the

laboratories of the railway companies, and of the large chemical and metallurgical works in this country. The author knows that the managers of these works would not readily be deprived of this check upon the deliveries of one of their most important and costly raw materials. The engineers of electric light and power stations, or of engineering works generally, would be wise to follow the same plan, and if their consumption is not large enough to warrant the engagement of an analytical chemist and the equipment of a laboratory for this work, they might with advantage send their samples of fuel to one of the numerous chemists who specialize in this class of work. The analysis of fuel and the determination of its calorific value is not work of a very simple character, and the author does not recommend engineers to attempt it themselves. Even in the matter of sampling, much care and attention is required if the sample is to be a thoroughly representative one, and the weight of fuel to be sampled is large. The idea of many engineers, that a shovel-full of fuel selected haphazard and placed in a box, is a sample, is somewhat childish in its conception. For the guidance of engineers in this matter, a set of rules to be followed in sampling fuel, are given in the Appendix to this paper.

II.—WATER SUPPLY.

Most engineers are now ready to recognise the value of analysis in connection with the supply of water for boiler purposes, and are prepared to admit the heat losses due to scale formation inside their boilers. It is therefore not necessary to discuss this point at any great length. Where the hardness of the water used for feeding the boilers is above 15 English degrees, equivalent, that is, to 15·0 grains of calcium carbonate per gallon of water, some form of water-softening apparatus ought certainly to be adopted. It is indeed questionable, whether such an installation would not also prove remunerative in large power stations, when the water employed is above this standard of purity. The author does not intend to discuss at length in this paper the subject of water-purification by chemical reagents, nor to describe the various types of softening apparatus now being placed on the market by engineering firms in this country. He is, however, in favour of external treatment of the water before entering the boiler, and does not approve the use of "boiler compositions." So far as his observation goes, the more up-to-date electricity generating stations in this country are well equipped with apparatus for this purpose, and many of the engineers of the

remaining generating plants would agree, that water-softening is an essential condition of fuel economy for both large and small power stations.

Lime, and carbonate of soda or caustic soda, are the usual chemicals used for water-softening. The amount of these which it is necessary to employ can only be determined by chemical examination of the feed-water. It is customary to base this calculation upon the results of one analysis only; but the examination should be repeated at quarterly or shorter intervals, for the character of the water supply may change, and the *appearance* of a water is no guide to its chemical constituents. Calcium carbonate and sulphate, and the corresponding magnesium salts, are all held in solution in water, and may increase greatly in amount without any change in the water becoming visible to the eye. Water drawn from brooks or rivers in the vicinity of the coast may also, at the times of flood or spring-tide, become contaminated with much sodium chloride, and this is another salt which should not be permitted to collect in any large amount inside the boilers, since it leads to pitting and corrosion of the plates.

Here again no change in the water can be detected by the eye; and chemical analysis will alone reveal the presence of this impurity in excessive amount. The author knows a case in which trouble of this kind occurred in an electric power station in this neighbourhood, and doubtless many engineers drawing their water for boiler-supply from surface streams, have experienced the same difficulty.

Periodic examination of the water used in the boilers by an expert chemist is therefore essential as an aid to economical steam production; and for most waters used for boiler-supply, treatment with softening chemicals will, as the result of this chemical examination, be found necessary.

(Exhibit Photograph showing lime deposit obtained from London water.)

III.—THE COMBUSTION OF THE FUEL IN THE BOILER FURNACE.

Coal may, for practical purposes, be regarded as a mixture of solid carbon and volatile hydrocarbons, with moisture and ash as impurities. The analyses given in the Appendix show how these four constituents vary in amount. Engineers have not sufficiently recognised the combustion difficulties due to the high percentage of volatile matters present in many fuels, and to the need for large combustion chambers to obtain perfect combustion in such cases.

The following experiments will make this need evident :—

Exp. I. Heat 1 gram of fuel in a closed Platinum crucible.

Exp. II. Show influence of air supply upon the flame of an ordinary Bunsen burner.

The perfect combustion of bituminous coal demands conditions which are not often met with in the modern boiler plant. These conditions are:—

(1) A sufficiency of air; but not an excess of the same.

(2) A sufficiently high temperature in the combustion chamber.

(3) A perfect admixture of the air and volatile hydrocarbons.

The first and second of these conditions are not always fulfilled in the ordinary working of boilers. Condition three is *seldom* recognized as essential; and where it is attained, it is more the result of chance than of design.

The supply of air to the boiler furnace is, of course, controlled by the fireman; and the tendency where no chemical examination of the flue gases is made, is—in large towns especially—to work boiler fires with a large excess, since it is more easy to get over the smoke difficulty in this way. Mr. Pritchard, in his 1902 Paper on "Fuel Economy," referred at considerable length to the losses due to this cause, and on page 139 of the Proceedings of this Society for the Session 1901-1902, you will find a Table compiled by the late Dr. Hurter, showing the percentage of fuel loss, with varying percentages of CO_2 in the waste gases passing to the chimney. With these exit gases at a temperature of 600 degrees F., the losses due to excess air may vary from 13 per cent. to 68 per cent. of the fuel burned. The latter loss is that represented by only 3 per cent. of CO_2 in the waste-gases, and is of course exceptional. But the author has many times found only 7 per cent. to 8 per cent. CO_2 in the waste-gases from modern boiler plants; and this shows a fuel loss of 25 per cent. —or double that which would be incurred, with more careful attention to this question on the part of engineer and fireman. The author does not propose to go into this question more fully, but in Table II. of the Appendix, figures have been given showing the estimated money value of the fuel losses due to this cause—namely, excessive draught; and two extracts from Mr. Stromeyer's 1902 Memorandum to the Members of the Manchester Steam Users' Association have been appended to it. Engineers of large electric supply stations would be wise to give this Table and the extracts their attention.

With boiler plants burning 50 tons of coal per day, a saving of £660 per year might be expected by careful supervision of this one point alone.

To sum up the position as regards excessive air supply :—

With careful firing and correct draught an average of 14 per cent. of carbonic acid should be present in the chimney gases. The ordinary percentage is far below this figure, and some authorities place the general average at only 8 per cent. This low percentage is due to excessive draught, and consequent unnecessary amount of air passing through the boiler flues. The result is a large increase in the amount of heat carried away by the waste-gases. The actual loss—represented by the difference between 14 per cent. and 8 per cent. CO_2 in the waste-gases with chimney gases at 560 degrees F.—is equal to 10 per cent. of the fuel burned in the boilers.

As regards the question of working boiler furnaces with too little air, and thus producing CO in place of CO_2 with consequent loss of heating effect (see page 137 of Mr. Pritchard's Paper), this danger is minimized by the fact that with the cheaper forms of fuel, smoke is always produced under such conditions ; and the fireman has thus a visible check upon his action in this matter.

It would, however, be of advantage if engineers in charge of boiler plants, would always arrange that firemen can see the chimney top without going outside the boiler house. When the plan of building construction is such that a direct view of the chimney is obstructed, reflecting mirrrors can be used at one or two points, to attain the desired end. Dampers that are in good working order, and that can be opened or closed by the fireman without leaving the firing plate of the boiler, are also an essential condition of proper regulation of the air supply, for with bituminous fuels the amount of air required for perfect combustion varies greatly at the different stages of the process.

The experiment of heating merely one gram of such fuel in a platinum crucible, has proved what an enormous volume of gas must be liberated within the furnace of the boiler within two minutes of firing, when fresh fuel of this character is charged on to the red-hot layer of coke lying upon the furnace bars. A new instrument for registering the draught—in the furnace and before the damper—called the Pyrimeter—has just been placed on the market ; and it is possible that the use of this by boiler engineers would also conduce to more efficient regulation of the air supply to the boiler fires. The instrument in appearance resembles the ordinary steam pressure gauge ; and an intelligent fireman would soon learn how to use it with advantage. Rule-of-thumb methods in the matter of air supply to boiler fires should certainly be displaced. The problem when burning bituminous fuels is much less simple than the ordinary fireman

realizes; and, as already pointed out, fuel losses that can rise to 15 per cent. or 20 per cent., may result from this one cause alone.

As regards the second condition of perfect combustion, viz.: *The maintenance of a sufficiently high temperature in the combustion chamber*, this is a condition absolutely essential in the burning of fuels containing 10 per cent. or over of volatile hydrocarbons; and it can only be ignored when using coke or anthracite fuels. Unfortunately, boiler engineers have not generally recognized this condition in the construction or setting of modern boilers, and nine-tenths of the factory-smoke produced in this country may be ascribed to the failure to maintain this condition within the boiler furnaces. The water-tube boiler makers are the chief offenders in this respect; and in most of their boilers as at present constructed and set, perfect combustion of the fuel can only be obtained when employing the high priced anthracite or South Wales steam fuels. When ordinary bituminous fuels are used in such boilers, the volatile hydrocarbons which distil from the grate, even when mixed with a sufficiency of air, are brought too quickly into contact with the boiler tubes, and the temperature of the gases is thus greatly reduced before perfect combustion has had time to take place. The following experiments will explain what occurs in this case. (Experiment III. with Bunsen flame and wire-gauze, and Experiment IV. with candle and copper spiral.)

These experiments prove conclusively that it is not sufficient to have a mixture of an inflammable gas and air for combustion to ensue. These gases must not only be mixed, but they must also be maintained at, or above, a temperature known as the *combustion temperature*. This temperature for the hydrocarbons distilled from coal, is given by different observers as between 504 degrees C. and 667 degrees C.

The obvious method of obtaining this temperature is to provide a combustion chamber, lined with some refractory and non-conducting material, which will not allow heat to be dissipated before perfect combustion of the gases has occurred. It is not the author's purpose in this paper to describe in detail the various types of internal combustion chamber, which may be adopted for preventing heat dissipation in badly designed boilers. It must suffice to state here that such boilers may be rendered suitable for burning bituminous fuels without any very great capital outlay, and that the results obtained, even with water-tube boilers, from the modified form of setting, are reported to be entirely satisfactory.

In connection with this branch of the subject, it may be pointed

out that the evaporative efficiency of a boiler is increased, by obtaining the highest possible initial temperature in the combustion process. According to Stromeyer (see page 9 of the 1902 Memorandum), the heat transmission between the water and the hot gases is directly proportional to their difference in temperature, and therefore the heat transmission is higher the greater this difference. Boiler engineers have as yet made no serious attempt to increase the temperature of the combustion process, by heating the air used in the boiler furnace.

When one sees the remarkable results and high thermal efficiencies obtained with the regenerative principle applied to glass furnaces, one is tempted to ask whether some of the heat permitted to escape with the waste gases from boiler plants could not be utilized in this way; and the author is of opinion that this subject is well worth the attention of boiler-engineers. Double-walled flues, and a chimney with an inner steel air-shaft, might solve the problem, but in this case forced draught would be necessary.

Turning now to a consideration of the third condition for perfect combustion, viz.:—*Perfect admixture of the air and volatile hydrocarbons*—here again we find the condition is imperfectly provided for, in the ordinary boiler furnace when burning bituminous fuels. The following experiments will illustrate the need for admixture of the air and hydrocarbons if perfect combustion is to be obtained.

(Experiment V.—Bunsen burner, with corroded tube.)

(Experiment VI.—Platinum crucible and 1 gram coal.)

It is evident that the mere opening by the fireman of the slide in the furnace doors, will neither provide the amount of air nor the admixture, requisite for burning the great volume of volatile hydrocarbons given off immediately after charging fresh fuel. Nevertheless, this is the only provision made in the ordinary types of boiler furnace. A supply of air, preferably heated, coming in behind the bridge or at the rear of the firegrate, is necessary in order to obtain perfect combustion, and this air must be distributed over the width of the furnace, in order to provide all portions of the mass of volatile hydrocarbons with the oxygen necessary for their conversion into carbonic acid gas and aqueous vapour. A secondary combustion chamber, walled with non-conducting material, is also necessary, in order to guard against loss of temperature before the combustion of these volatile gases is completed. The higher the percentage of volatile hydrocarbons in the fuel, the larger will be the space required for perfect admixture and combustion of these products. The neglect of boiler-engineers to provide for the

combustion of these volatile hydrocarbons, save in the case of one or two special types of boilers, has led to the invention (?) of a number of patented smoke prevention appliances (some good and some bad), which would have been utterly uncalled for, had a little more knowledge of chemical science been included in their educational curriculum.

The author may summarise this portion of his paper by stating that the three conditions essential for the perfect combustion of bituminous fuels, can be maintained even in boilers of the water-tube type, when burning soft or bituminous fuels. When engineers recognise this fact clearly, and act upon it, we shall have less cause to complain of smoke in our towns, or to indulge in smoke prosecutions against the worst offenders, generally electric light and power stations, in our great cities.

IV.—THE WASTE GASES.

From what has already been said under heading III, it will be gathered that the regular and systematic examination of the waste-gases passing from boiler-plants is absolutely necessary for the attainment of the highest possible efficiency with the fuel used. Such examination should include the temperature of the exit gases—the draught behind the dampers—and the chemical constituents of the gases. At present the boiler-plants in this country where such systematic examination is carried out are comparatively rare, and as regards electric light and power stations, the author knows of only two cases in which this method of checking the work of the firemen is employed.

As regards the temperature determinations, these may be made either with the electrical resistance thermometers of the Chatelier type, or with ordinary mercury thermometers—reading up to 550° C. —equal to 1022° F.

A recording form of resistance thermometer has also now been placed on the market, and with this apparatus a continuous record of the temperature of the exit flue-gases can be obtained, with little or no expenditure of time on the part of the engineer in charge. For works use, a Water Pyrometer is also of some advantage, more especially for determining *roughly* the temperatures in places where a mercury thermometer could not be safely employed, or for determining temperatures much above the limit which is possible with such a thermometer.

(Exhibit and describe use of a Water Pyrometer.)

For the measurement of draught, an ordinary water-gauge may be

used, or the instrument known as the *Pyrimeter*, already referred to, may be employed.

The chemical constitution of the exit flue-gases may be ascertained with various forms of apparatus, but none of these, it may be remarked, will yield valuable results unless considerable thought, care, and attention, have been given to the sampling of the gases. A sampling hole, for drawing samples, ought to be left at the time of setting in the top or side flue-walls of each boiler, at that point where the boiler exit-flue joins the main flue to the chimney. A 30-inch length of wrought iron pipe, one-inch in diameter, with a flanged top, should be set with fire clay in this hole, and cotton waste or an iron plug should be used to close the end opening to the air. When a sample of flue-gases is required such a sampling hole is always ready for use, and valuable time is not wasted in looking for the place, or in clearing the accumulated rubbish from the hole when found. The author could enlarge greatly on the subject, if he desired, as he has suffered much from the neglect of boiler engineers to provide proper sampling places in their flue walls. The use of a large aspirator containing water (see Mr. Pritchard's Paper, page 138) cannot be recommended for collecting an average sample of gases over long periods, as carbonic acid gas is slightly soluble in water, and the absorption with a sample of gases, containing 8 per cent. or more of CO_2, is noticeable in a few hours. The better plan for collecting an average sample of exit gases is to use the method described in the Proceedings of the Institute of Civil Engineers, Vol. CL., pages 261-264. A reliable average sample of the flue-gases passing a given point in two or three hours is, however, exceedingly difficult to obtain, and the author recommends in preference a series of snap tests at short intervals of time. The average of these results gives a far more reliable check upon the work of the boiler and fireman. The best apparatus for taking such snap samples is a rubber finger pump, provided with a simple form of stop-valve for preventing any leakage of air past the valves of the pump, which are never perfectly tight. (Exhibit Gas Sampling apparatus of this kind). The sample of gas obtained in this way can be kept for many hours without suffering any change, since the amount of moisture which condenses on the interior walls of the glass sample tube, is not sufficient to absorb any material volume of CO_2. A sample tube provided with glass stop-cocks must, however, be employed, if the sample of gas is to be preserved some time before analysis. If it be examined at once, a tube closed with rubber, and ordinary spring clips, may be employed with safety for this work.

The complete examination of flue gases for CO_2, CO, and O, is most conveniently carried out in the Orsat-Lunge form of gas-testing apparatus.

Several forms of recording CO_2 apparatus have also been invented, and are in successful use in several works in this country, in America, and in Germany. They yield valuable information, but require careful attention, and the results require checking by independent tests at intervals of three or four weeks. (Exhibit Diagram obtained with Recording Pyrometer and Gas Composimeter.)

For works' use the author has designed a form of apparatus which he considers will yield valuable results in the hands of intelligent engineers in charge of boiler plants. (Exhibit and describe modified form of Honigman's CO_2 testing apparatus.)

This apparatus may be employed for checking the results obtained with the recording forms of apparatus already referred to, since in the hands of a skilful operator the margin of error is below ·50 per cent. on the CO_2 present in the exit gas. The absence of any liquid and its compactness when dismounted and packed in its case are two other points which should recommend it for works use.

V.—CONCLUSIONS.

The author in this paper has attempted to prove that there is considerable scope for economy in the working of most boiler plants, and that more attention to the chemical side of the question on the part of engineers, would materially reduce their annual expenditure upon fuel. In the most interesting address delivered by our President a fortnight ago, some figures were given showing that the *works costs* per B.O.T. unit of electricity, generated in some of the best managed stations in this country, varied from ·52d. to ·70d. ;—the average for the six stations referred to on pages 22 and 23 of Mr. Miller's address being ·62d. The fuel costs per unit for the same six stations varied from ·19d. at Glasgow to ·41d. at Bootle ; and the average for the six stations is ·29d. per unit. Fuel, therefore, in some of the best managed and most up-to-date electricity supply stations in this country is accountable for nearly one-half the total works costs (46 per cent.) ; and any proposals for reducing this item of expenditure should receive the most careful consideration from electrical engineers. The total expenditure upon fuel per year in these six electrical supply stations, calculating from the aggregate output given in Mr. Miller's tables (36,975,000 B.T. units), must have been nearly £38,500, and if the author's assumption be correct, that 20 per cent. of this fuel might be

saved by greater attention to the chemistry of fuel combustion, the annual saving in £ s. d. would be represented by nearly £8,000. As evidence of the present wide variations in fuel costs, some figures taken from the *Electrical Times* tables of electricity works costs have been gathered in Table III. of the Appendix, and it will be noticed that the fuel costs per B.T. unit vary from ·19d. to 1·85d. per unit. It is hardly possible that the differences in the original cost of the coal delivered in the bunkers should account for such wide variations in these figures, and we can only suppose that in some of these works the heat losses due to bad management of the boiler plant are much greater than the 20 per cent. which the author has charitably assumed to be the case.

The steam-raising trials made with mechanical stokers also serve to indicate that the fuel efficiencies obtained in most boiler plants, working under normal conditions, are much below the maximum possible. The author is aware that the results obtained in these trials are looked upon with suspicion by many engineers. But, although it is improbable that these high efficiencies could be regularly maintained under actual working conditions, they are useful as showing what can be achieved when scientific supervision of the boilers is carried on from hour to hour, and when chemical tests of the flue-gases are used as a check upon the work of the firemen. The high evaporative efficiencies obtained in such trials are, in the author's opinion, due rather to these conditions, than to the fact that a mechanical stoker has been substituted for the human machine. An intelligent fireman is equal to, if not better than, any mechanical stoker. As examples of what can be achieved under the most favourable conditions the following figures may be given :—

Place	Boiler	Stoker	Results
Bristol ...	Babcock & Wilcox	Koker ...	11·20 lbs. water per lb. of fuel, from and at 212 degrees F.
Belfast ...	Do.	Bennis ...	11·96 lbs. do.
—	Solignac	Hand-fired	10·84 lbs. do.

With these figures it would be useful for engineers to compare the results obtained in their own works. The author was recently told by the engineer in charge of one of the finest and largest electricity supply stations in Lancashire, that the average evaporative efficiency of his boiler-plant was only about 7 pounds water per pound of fuel;

and Mr. Pritchard quoted a case in his 1902 Paper upon this subject, in which 15 pounds fuel were used to obtain one I.H.P. hour at the engine.

Another aspect of the subject which also deserves consideration, is that of the bearing of this waste of fuel upon our position as a manufacturing country. We hear a great deal at the present time about the unwisdom of exporting millions of tons of fuel per annum, and thus lessening our reserves of this valuable raw material. We hear too little, however, about the millions of tons which are annually "*wasted*" by users in this country. Supposing the author's estimate of 20 per cent. loss to be correct (and most engineers would admit that as regards factories and works this estimate is, if anything, too low), the weight of fuel which is wasted at the present time by unscientific use in this country must amount to 34,000,000 tons per annum. (The average home consumption for the years 1897-1900 was about 170,000,000 tons per annum.) This waste of a raw material so essential for our manufactures—the reserves of which will not last this country for ever—is sheer folly, and it ought to be checked with the least possible delay.

In conclusion, the following extract from the 1902 Memorandum of Mr. Stromeyer may be quoted; since it proves that others beside the author of this paper are of opinion that boiler engineers have somewhat neglected the chemical and scientific side of boiler-management and fuel economy.

The wish of all steam users is to have a boiler which, under normal conditions of working, will give highly economical results; and by normal conditions they mean, that the fires are to be worked by an average fireman with no one to tell him when he is wasteful, and with no one to explain how to be economical. This is a method of procedure which manufacturers would not tolerate for an instant in any of their producing departments. It is true that boilers cost money and never show a direct profit, and are, as it were, past praying for; but surely their expenditure on fuel amounting to from £200 to £500 or more per annum, ought to be carefully looked into and reduced to a minimum. This can only be done if steam users will either take the necessary trouble themselves, or at least employ some man who is capable of deciding whether a boiler is, or is not doing its duty; and, if not, he should be capable of showing what is wrong and what should be done. . . . . .

Seeing that the efficiency of some boilers exceeds 80 per cent., while that of others is less than 60 per cent., there is every prospect that with care the efficiency of the average boiler can be increased one-sixth, which means that if the present coal bill of an average boiler is £350, it can be reduced to £300 or less.

APPENDIX.

Extracts from Mr. E. C. Stromeyer's 1902 Memorandum to the Members of the Manchester Steam Users' Association.

On examining the trials summarised in the late Mr. Byran Donkin's work on the "Heat Efficiency of Steam Boilers," it was found that whereas the results obtained by different experimenters on one boiler installation agree fairly well, the results obtained at other installations of exactly the same type of boiler, are most erratic and even conflicting.

Thus, if we confine ourselves to Lancashire boilers, of which about 150 tests are recorded, we find enormous variations in the efficiency of boilers worked under practically identical conditions. For instance, in two cases of hand-fired Lancashire boilers, No. 7 and No. 57 in Mr. B. Donkin's Book, both burning English coal, the former at the rate of only 13·8 pounds of coal per square foot of grate, against 16·5 in the latter case, and evaporating only 3 pounds of water per square foot of surface, against 5·6 pounds, we yet find that the efficiency of the lightly-worked boiler No. 7 is only 53·7 per cent., against 71·6 per cent. in the case of No. 57 the hard-worked boiler. Again, comparing the two other tests, No. 12 and No. 67, we find the hard-worked boiler to be the more inefficient of the two, the performances being in the ratios of 53·2 and 74·8.

Evidently these anomalies depended either on the experimenters, or on the conditions of firing. The recorded trials were therefore subjected to a careful analysis, and those in which the experimenters might be considered at fault, or in which their data were incomplete, were rejected. By this means the total number of about 340 boilers of customary types was reduced to a very few, more especially as when making the calculations, it was found that the data must have been incorrect, some boilers appearing to have received heat from outside, instead of losing some by radiation.

TABLE I.—APPROXIMATE ANALYSES, CALORIFIC VA
OF VARIOUS ENG

General Description of Coal	1 Particular Description of Coal	2 Per Cent. Moisture	3 Per Cent. Ash	4 Per C Co
Hard South Wales Coals	Eaglebush	1·05	14·25	86·
	Dynevor Duffryn (1)	1·35	10·75	86·
	Standard Merthyr (1)	1·21	8·85	84·
	Do. (2)	1·27	12·45	85·
	Cwmmer Main (1)	1·46	10·00	87·
	Do. (2)	1·45	5·55	87·
	Dynevor Duffryn (2)	1·25	8·10	84·
	Do. (2)	1·20	9·75	87·
	Pontardame Smokeless (1) ...	2·66	8·40	87·
	Do. (2) ...	4·48	15·25	88·
	Do. (3) ...	3·65	13·05	87·
	Ocean Small Steam	3·13	13·95	87·
	Loughor & Mynydd Newydd ...	2·20	17·05	86·
	Werfa	1·34	14·95	90
Soft Bituminous Coals	Cannock Seam	10·62	23·05	70
	Kingswinford Slack	11·54	12·45	72
	North Hetton (1)	2·51	13·80	69
	Madeley Washed Slack ...	3·20	6·20	66
	Stopford Slack	7·83	9·45	66
	Bowley Washed Slack	2·76	5·85	67
	North Hetton (2)	2·94	11·40	69
	Wigan (1)	4·94	16·85	69
	Wigan and Skelmersdale (1) ...	6·76	16·50	71
	Wigan (2)	3·56	14·50	70
	Wigan and Skelmersdale (2) ...	3·76	14·20	69
	Digby Bright Peas	10·44	6·50	63
	Shipley Peas	7·72	7·75	66
	Marchay Rough Slack	7·80	3·05	64
	Manners Peas	7·44	10·75	66

NOTES.

(1) The results in columns 3, 4, 5, 6 and 7 are all based on the sample dried at 110 deg

(2) Columns 7, 8 and 10 give the calorific values in Centigrade units.

ULATED AND OBSERVED), PRICES, AND COMPARATIVE COSTS
WELSH COALS.

5	6	7	8	9	10
ent. Matter	Per Cent. Fixed Carbon	Calorific Value (observed)	Calorific Value (calculated)	Price per Ton delivered in Bunkers	Calorific Value per Penny of cost
				s. d.	
0	72·45	7,503	—	17 9	35·2
0	75·65	7,935	—	18 2	36·7
0	75·65	7,942	7,950	21 0	31·5
0	72·95	7,717	7,641	21 0	30·6
0	77·50	7,935	7,855	17 3	38·3
0	82·05	8,280	8,247	17 3	40·0
0	76·00	7,987	8,028	19 1	34·8
0	77·65	7,762	7,875	19 1	33·0
0	79·50	7,875	7,995	17 3	38·0
0	72·95	7,537	7,398	17 3	36·3
0	74·35	7,650	7,583	17 3	36·9
0	73·05	7,590	7,511	15 10	39·9
0	68·95	7,360	—	9 6	64·5
0	75·05	7,331	—	11 11	57·2
5	47·10	6,382	—	6 9	78·7
0	59·65	7,297	—	8 6	71·5
0	55·20	7,590	—	11 10½	53·2
0	60·50	8,365	8,041	10 6	66·3
0	56·65	7,590	—	7 5	85·2
0	61·55	8,365	8,123	10 6	66·3
0	58·30	7,790	7,658	11 10½	54·6
0	53·05	7,192	7,089	8 3	72·6
0	54·70	7,245	7,203	8 4	72·4
0	55·60	7,537	7,369	8 6	73·8
0	55·40	7,590	7,370	8 4	75·9
0	57·00	7,935	7,703	7 9	85·3
0	58·25	7,891	7,764	7 11	83·0
0	61·65	8,314	8,214	8 8	79·9
0	55·65	7,675	7,490	7 5	86·2

e samples marked 1, 2 and 3 are different samples of the same coal.

e first 12 samples are from a South Coast Electricity Supply Station and the costs delivered in Bunkers are correspondingly high.

Table II.

Money Value of the Fuel Losses due to Excess Air in the Exit Gases from Boiler Plants, when these contain only 8 per Cent. CO_2.

Tons of Coal burnt per day of 24 hours	Wasted Fuel		Money value of loss per Year
	Tons per day	Tons per Year of 330 working days	
			£
10	1	330	132
25	2½	825	330
50	5	1,650	660
75	7½	2,475	990
100	10	3,300	1,320

Extracts from Mr. C. E. Stromeyer's 1902 Memorandum to the Manchester Steam Users' Association.

It is evident, therefore, that far greater losses can be incurred by bad stoking with excess of air than with too little air, and there is, therefore, no harm in aiming to attain perfect combustion, more particularly as smoke at once reminds one that the combustion is growing too imperfect. This advice does not apply to gas-fired boilers. Gas being smokeless would not be visible, though it travelled up the chimney unburnt. Gas firing has, therefore, always to be regulated by analysis of the waste products. . . . . .

Perfect combustion is of far more importance, both as regards the efficiency of a boiler and the power to be got out of it, than is within limits, either the amount of heating surface or its arrangement.

Table III.

Fuel Costs per Board of Trade Unit in 14 Electricity Supply Stations.

Name of Undertaking	Total Works Cost in Pence	Fuel Costs in Pence
Monmouth	1·26	·19
Liverpool Overhead Railway Co. ...	·77	·20
City & S. London Railway Co. ...	1·05	·31
Glasgow	·95	·36
South Shields	·76	·37
Southport	·85	·37
Central London Railway Co.	1·32	·53
Blackheath	1·04	·59
Harrogate	1·54	·79
Lambeth	1·69	1·04
Metropolitan	2·22	1·32
Kingston	2·32	1·54
Beckenham	2·45	1·75
Dublin	3·24	1·85

From "Electrical Times" Tables.

Goutel's Formula for Calculating the Calorific Value of Fuels, from the results of the Approximate Analysis.

$$P = 82\,C + a\,V.$$

P = Calorific value in centigrade units.

C = % fixed carbon. V = % volatile matter.

a = a variable coefficient, depending upon the amount of ash and moisture in the fuel. Using the formula $V' = \dfrac{V \times 100}{C + V}$, the following values are obtained for a:—

V' =	5.	10.	15.	20.	25.	30.	35.	38.	40.
a =	145.	130.	117.	109.	103.	98.	94.	85.	80.

"Comptes Rendus," September, 1902.
"Sc. Abstracts," No. 252, 1903.

Rules for Sampling Fuel.

As each barrow load or fresh portion of fuel is taken from the pile or store heap, a count is kept of the number used, and *the whole contents of each tenth or twentieth barrow or portion* are placed on one side, in a cool place, under cover. Care must be taken that the barrow or portion selected for the sample does not contain an unfair proportion of lumps or smalls.

At the end of the day, or period for which the sampling is to be carried on, the heap of fuel obtained for sampling purposes, as described above, is transferred to a sampling plate, and the larger lumps are all crushed down to walnut size. Should no sampling plate be available, four of the iron plates used for covering manholes and boiler-flues may be utilized to obtain a *hard clean* surface on the floor of the boiler-house, and the crushing down of the sample may be carried out on these plates, with any heavy and flat lump of iron at hand. The heap of fuel, after this first crushing, is thoroughly mixed by turning over and over with a spade. The heap is then flattened down, two lines are made across it at right angles with the edge of the spade, and two of the four opposite sections are selected to form the reduced sample.

The lumps in this are again crushed, the sample is again mixed, and the quartering operation repeated, until about 8 or 10 pounds of fuel only remain, with no lumps that will not pass through a $\frac{1}{4}$-inch sieve. Two one-pound tins, with ordinary or patent lids, are filled from this remaining heap of fuel, after thoroughly mixing the same with the hands or with a small shovel. One of these tins is to be sent per parcels post to the fuel expert for analysis; the other is to be kept for reference in case of dispute.

DISCUSSION.

Mr. J. A. F. Aspinall said—The author of the paper wrote to me a few days ago and asked me what we had done with respect to the analysis of coal on our railway, and, thinking that it might be interesting to him and to the gentlemen present, I have this evening exhibited a diagram which gives the record of the analyses of our coals used over a considerable number of years, and shows that we really do in the ordinary course what the author advocates in his paper. You will find that on the diagram the fixed carbon, volatile matter, &c., are given, and the percentage of sulphur. When using with copper fire boxes and copper or brass tubes the sulphur has a very serious effect. On the diagram there will be found many varieties of coal from Lancashire, South Wales and South Yorkshire, and it is interesting to see the high percentage of carbons you get in the South Wales coals, and coming next you will find the South Yorkshire coals. Mr. Aspinall

I quite agree with what the author has said as to the necessity for careful analysis. When using, as we do, 2,000 tons of coal a day, it is a very serious matter if we do not get the right kind of fuel.

I agree with the author's remarks as to the great variation in the quality of Lancashire coals, and I suppose the same may be said, though to a lesser extent, as to South Wales and South Yorkshire coals.

The author has mentioned the use of an instrument recording the temperature of gases in flues, and I may say we have in use an instrument of the kind known as the "Ados," which produces a record every few minutes.

I believe there is a book which is called "Every man his own Lawyer," which is said to have produced more fees to barristers than any book that is known. This apparatus makes, I suppose, every boiler its own chemist, and I agree that probably it is necessary, to avoid mistakes, to have these careful tests mentioned by the author. However, the information given to me with regard to it is that it is very satisfactory and has given good results so far on our boilers.

As mechanical stoking has been mentioned, I would like to say that in many cases I have known, where mechanical stoking has been employed without careful enquiry as to whether it was suited to the cases in point, the probability has been that a great deal more money

Mr. Aspinall has been thrown away in coal than ever was saved in labour, and if mechanical stoking is to be employed at all, the circumstances under which it is to be used have to be much more carefully considered than they have been in these cases I have known, and I should not be surprised if some of the poor results spoken of here have been due to the injudicious use of the mechanical stoker.

Mr. West Mr. HENRY H. WEST said—I am afraid I can say nothing which is useful, but there are two or three points that have occurred to me during the reading of the paper which it may be of interest to draw attention to.

In most goods that are sold some sort of test takes place to ascertain whether the goods supplied are equal to sample, and I was very much struck with the remark on page 29 that engineers, as a rule, do not take any trouble to ascertain that they get what they have paid for. I very frequently find that though we have excellent coal supplied to us at times, there are other times when it drops off to a very much inferior quality than the sample submitted, and on which our contract was based.

The reference which the author makes to the admixture of air reminds me of the experiments made by Mr. Charles Wye Williams, of the City of Dublin Company, 50 years ago. He endeavoured by dividing up the air into small streams to get a more complete admixture than could be obtained by allowing it to go into the fire in large volumes, and his results were certainly very satisfactory ; but I remember trying it myself on the East coast of this country. I put in a split bridge to admit the air in a thin film more or less heated by its passage through the bridge, but the difficulty I experienced was that, after a very short time, the air-slots were entirely choked up with dust and were useless, and I could not devise anything which would keep them as clear as they ought to be.

Mr. Johnson Mr. JOSHUA JOHNSON said—I should like to say that I agree with the author of the paper that engineers, as a rule, do not get to know the condition of the fuel they are using. They are supplied with a good sample to start with, but afterwards, as the author says, they do not obtain the same quality, but get a very inferior supply. When I say this I am speaking as far as my experience goes, generally, of engineers, but particularly in connection with Electric Light Stations.

The author, in his paper, says something about mechanical engineers not being well up in electrical matters, but it is the general opinion among mechanical engineers that electrical engineers have not

sufficient mechanical knowledge. Whether that has anything to do with the fact that they do not get their fuels tested, I do not know. Mr. Johnson

But there is one point which affects the engineer and that is the fact that there are committees to deal with. My experience goes to show that in some cases, at any rate, a committee exercises too much control over the engineer. There are many points that committees do not fully recognise the importance of, and they only look at the price of the fuel. They do not look at the price compared with the quality—a very important matter—and I have known instances where threepence per ton has settled the contract when the fuel was worth 2s. per ton less.

The matter of mechanical stokers has been mentioned, and I am sorry to hear Mr. Aspinall's opinion, but, as showing that that is not altogether the experience throughout the country, I may mention the fact that one of the largest and best paying chemical manufacturing concerns in this country uses mechanical stokers, not only to all their boilers but also to their evaporating pans. There is another concern up in the North of England in which experiments have been made only last week with mechanical stokers, and they are burning 168 tons per week under one boiler, and obtain an average of 13 per cent. of CO_2 during the whole of the week.

I quite agree with the author in referring to the fact that engineers are very chary of accepting tests with the mechanical stoker, because a great many of these tests are of very short duration, and we know that many errors can crop up, intentionally or otherwise. In fact it is within my experience that short tests conducted like that have been intentionally made to produce very good results which have never again been obtained, so that engineers have some room for doubt on this subject.

There is one point I do not agree with, and that is that a good fireman is equal to a mechanical stoker. It is possible you may get a very good fireman who will approach very nearly to a good mechanical stoker. At the same time he is a very rare bird. You can get mechanical stokers, I believe, to do the work—especially when it is regular—a great deal better than you can get a fireman to do it, because you can regulate the supply of fuel and the position of your damper; and that is a point to which engineers do not always pay sufficient attention. I have known cases where a damper has been kept fully open whether it is necessary to burn the quantity of fuel or not.

Mr. Johnson

But in the case I have referred to in the North of England, where they are burning a ton an hour, there cannot be much waste.

I have known other places where they have practical chemists on the works, and one of these regulates the height the damper must be used at and also regulates the amount of fuel the mechanical stoker must use, and he knows that he is getting the best results. That is a case in point where a fireman would not be able to obtain results equal to a mechanical stoker.

There is another point, and that is the matter of firing the boilers. We know, of course, of a great many instances where engineers say that they require to get a certain duty out of a boiler, but they do not consider at what cost they are doing it. We have known instances where the gases have been tested and were found to be going up the chimney at a temperature of 900°, simply because the boiler was required to raise more steam than it was built for, the result being excessive waste of fuel.

Mr. Aspinall

Mr. J. A. F. ASPINALL said—I am sorry if there is any misapprehension as to what I mean with regard to mechanical stokers. I do not mean to say that mechanical stokers are always undesirable things, but what I mean is, where the load is varying, and you use a mechanical stoker, you may use a great deal of fuel thereby. In many places, where the load is constant, the mechanical stoker may do very good work, but where the load is up and down, a mechanical stoker becomes a very expensive thing.

Mr. Thomson

Mr. G. CARRUTHERS THOMSON said—I can fully endorse the conclusions that the author has brought forward that we must have plenty of room for combustion. That, in the majority of boilers, is the great failing. However, that is getting better in the Lancashire boiler. Where they used to put in three furnaces in the Lancashire boiler of 9 feet diameter, they only put in two larger furnaces and the results are more satisfactory, simply owing to the better conditions for combustion.

One great fault in boiler setting is making the flues too small, under the impression that the draught will be spoiled, and in many cases, where the steam supply is deficient, rebuilding the flues and the boiler setting will solve the difficulty and use no more coal.

In other cases, where the flues and setting are large enough, but difficulty is found in meeting the demand for steam, the addition of another boiler will give an ample steam supply with no increase on the fuel bill.

I have known several cases where both of the above methods gave

good results, both for quantity of steam and cost of fuel, and where the saving thereby induced has paid for the alteration within a year of completion where the cost of the fuel was much less than in this district. Mr. Thomson

Then in regard to the water, it makes a very great difference whether you have a deposit in the water or whether you have none. Feed waters for boilers should have no deposit behind and it pays to remove depositable matter from the water.

In regard to mechanical stokers and hand-firing, you require a good man if you are to get the value out of your mechanical stoker, and you require a good man if you are to get good results out of hand-firing, and unless you get a good man and pay him well, you can never get good results; and the variations in the efficiency of firemen when hand-firing are even greater than the author has pointed out. The same thing applies to the mechanical stokers, you require a man of more skill for mechanical stoking than you do for hand-firing. I know of more than one good mechanical stoker on the market that are unsuccessful because they cannot get men who will take the trouble to study them and work them, and the engineers and firemen who have charge of them will not take the trouble to do so.

In regard to gas-firing, I see in the Appendix that when gas is used as fuel there is no smoke. I have seen boilers fired with gas and I generally found that they were as good for making black smoke as any other sort. I have never been able to find in the flue gases such a small quantity of carbonic acid gas as I have found with the use of the mechanical stoker, and this I attribute entirely to the want of skill in the firemen or their negligence in keeping sufficient ashes at the end of the firebars, thus allowing too much cold air to pass through the flues.

In the majority of factories and in most places where coal is used, there is far too little interest taken in the stoking department, because, in a great many places, the fuel bill is a very small item in the case of production of the article that is manufactured, and they say, "We don't need to bother, as the coal bill only costs a fraction of a 1d. a ton."

An engineer has no chance in such a case, and until you get manufacturers and factory owners educated up to these little economies you will make no progress in reducing the waste of fuel and in the emission of black smoke from factory chimneys.

Mr. P. B. Coulston said—I would like to know if the author could Mr. Coulston

Mr. Coulston give us any particulars as to the quality of the water at Belfast and Bristol, mentioned on page 41, with the hand-fed stokers. I think, from my knowledge of the subject, that the quality of the water is an important point and would have a considerable effect on the result.

Mr. Miller The President, Mr. T. L. MILLER, said—Before calling on the author to reply to the discussion, I would like to make one or two remarks on the very interesting paper he has given us, a paper which, dealing as it does with this question of fuel economy, cannot fail to be of interest to the majority of our members.

In dealing with this subject the author has not limited himself to the question of the combustion of fuel, but has also dealt with the great losses which may be entailed owing to the use of unsuitable feed-water, and in this connection I do not think engineers, as a body, quite appreciate the very large increase in the coal bill which may be caused by a comparatively small deposit on the boiler heating surfaces.

I am in full agreement with the author with regard to the value of the analysis of water supply for boiler purposes and with the chemical treatment of the same. The trouble has been, however, that most of the apparatus supplied for water softening requires a certain amount of attention which, in many cases, it fails to get. When under the eye of the maker the apparatus no doubt fills all the conditions required of it, but in actual work the results frequently fall far below those obtained on test.

Dealing with this question of fuel analysis the author has given us his views as to the value of fuel analysis in great detail, but there is one question in connection with the fuel supply on which he has not touched, and which, I think, demands attention from all engineers using large supplies of fuel, and that is not so much the *quality* of the fuel but the *correct weight* of the fuel delivered. From my own experience I have found that where fuel is delivered into works in large quantities without previous weighing there is frequently a considerable shortage in the amount, and in order to guard against this I think arrangements should in all cases be made for the weighing of the coal prior to its delivery.

On page 37, the author, dealing with the question of boiler setting, remarks that when one sees the remarkable results and high thermal efficiencies obtained with the regenerative principles applied to glass furnaces, one is tempted to ask whether some of the heat permitted to escape with the waste gases from boiler plants could not be utilized in this way. I remember in the early "eighties" having to deal with a boiler plant in which an attempt was made to use the

regenerative principle. It was an externally fired boiler with the air supply heated by being taken through passages in the brickwork setting, and the furnace itself was made in the form of a reverberatory furnace. We got very intense heat, but were troubled with the rapid deterioration of the boiler plates, due to the intensity of the heat, and this is what you are liable to in working on the regenerative principle, and particularly when water of an inferior character is used. Mr. Miller

Later on the author refers to the admission of air behind the bridge. This is quite common in Lancashire boilers, only that the control of the supply of air is usually left to the stoker, who has very little scientific knowledge, and who, as has already been pointed out, is but a poorly paid man, and it is to this fact that I think the failure of most of these arrangements is due.

Referring again to the supply of heated air behind the bridge, I might remark that in the early "eighties" one of our Past Presidents, Mr. William E. Mills, read a paper before this Society descriptive of the Mallett system of controlled combustion, from which, I believe, extremely good results were obtained. In this system hollow fire bars were used, a practice which has since been adopted in this country with, I believe, satisfactory results.

With regard to the question of mechanical stokers, there is, as we have seen to-night, a difference of opinion. Where, however, there is a large range of boilers, and where the work is fairly constant, mechanical stokers will no doubt give very satisfactory results, but where, as Mr. Aspinall has pointed out, you come to deal with varying loads, the results are not so satisfactory. In this connection, however, the question of value obtained for the capital expended is important, as while with a constant load the saving effected in fuel and labour may warrant their use, it is quite possible that under light and varying loads the amount required to cover the charges for interest and sinking fund may be more than the saving effected in the fuel and labour costs.

Turning now to the author's remarks as to the costs in electricity supply works, and more particularly with regard to the Appendix, I would point out the great difficulty in making comparisons, unless the conditions of supply are fully set out. In an electricity supply works the fuel costs depend upon (1) the cost of fuel to be obtained in the district; (2) the system of supply adopted; (3) the load factor; (4) the class of engines, and (5) the personal factor of the engineer in attendance. From this it will be seen that unless each of these factors receive consideration no true comparison can be made with regard

Mr. Miller to the fuel costs in different undertakings, a fact which is frequently lost sight of in making comparisons of fuel costs in different stations.

Mr. Kershaw MR. KERSHAW, in reply, said—I am very much obliged to you for the attentive hearing you have given to me, and to the gentlemen who have made the evening interesting by their contributions to the discussion of my paper.

Mr. Aspinall has made only one remark with which I require to deal, but I must first thank him for bringing this very interesting chart to illustrate my remarks on the analysis of coal. With regard to mechanical stoking, I do not think, and many of the speakers have agreed with me in this, that sufficient attention has been given to the training of stokers. There is scarcely any work going on inside a works or factory that requires more scientific knowledge or more skilful labour.

With regard to Mr. West's remarks, he says that engineers do apply tests to raw materials, and he seems rather grieved with my criticisms on this subject. Well, I can only speak of what I know from actual enquiries, and the number of works engineers whom I have found to be regularly testing their coal supplies might be counted on the fingers of one hand.

Mr. Johnson refers to the lack of mechanical knowledge on the part of electrical engineers. I think most electrical engineers will admit, after a few years experience of station management, that their mechanical and general training has been deficient, and that too much time has been spent on electrical subjects.

Mr. Thomson dealt with the question of mechanical stokers. Mr. Thomson, of course, supported me in stating that stoking is most skilful work, and that sufficient attention is not given to the subject by engineers.

Then, Mr. Coulston asked me as to the water used in the tests given on page 41. I am sorry I cannot give this information, as these trials were not conducted under my own supervision. I would like you to notice, however, that the third test, namely, that of the Solignac boiler, was conducted with hand-firing, and that the evaporative efficiency is almost as high as in the two mechanical stoker trials.

The President has kindly made some remarks. He says, with regard to fuel, that it is very important that the weight of the fuel should be tested, but recommends this, not as a substitute for, but as an addition to, the tests of its quality. With regard to the regenerative principle

applied to steam boilers, you could undoubtedly get very high temperatures and your plates might suffer. But if it were generally understood by boiler engineers, that such temperatures were to be employed, they could, I believe, produce at the present time plates which would stand the temperatures required. Mr. Kershaw

With regard to the figures in Table III, the President speaks, of course, with expert knowledge. I dare say it is not fair to compare these figures for fuel cost without knowing what kind of a load the stations have to carry. I admit that, on this point, he knows very much more than I do myself.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

THIRD MEETING—2ND DECEMBER, 1903.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,
PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. LYON H. MAXWELL and R. S. MCLEOD, as *Members*.

RECENT TELEPHONE DEVELOPMENTS IN LIVERPOOL.

BY E. J. HIDDEN,
District Manager, National Telephone Co., Ltd.

IN accepting our President's invitation to read a paper before you, the subject of which should be Telephones, the author was somewhat exercised in his mind as to what particular branch of telephone work he should deal with. There are so many problems connected with the details of the work, of which the majority have so little knowledge, that he felt sure whichever branch he was privileged to put before you would be of considerable interest. However, as an Engineering Society, perhaps recent engineering work in connection with both the line or outside work, and the switchboard or inside work, will appeal most to the majority of the members.

In the early days of telephony each subscriber was provided with one wire only (and that made of iron) to the Exchange, the return from the Exchange to the subscriber's instrument being made through the earth. With the increase in the number of telephones, and the disturbing influences of earth currents, and induction from foreign wires, such as telegraph wires, and wires carrying heavy currents, the metallic circuit, or twin wire, was brought into use, the conductors

used being of copper or Silicium bronze. This large increase in the number of the wires necessarily meant heavy pole routes, and the attendant difficulties to maintain through high winds and the care to be exercised in regulating the wires affected by the change in temperature. It became, therefore, necessary to adopt some method that would reduce or do away with these heavy routes, and at the same time not reduce the efficiency in the speaking properties.

There were two methods by which this result could be accomplished: by means of overhead cables containing a quantity of wires collected together, or by cables run in conduits underground. The latter system was adopted, and, though the work of placing the wires underground is by no means finished, the result has been to bring the complaints due to interruptions on the outside lines down to a minimum and so improve the efficiency.

The system adopted in Liverpool and district, is to run out cables from the Exchange in concrete blocks, or pipes, laid in trenches, which are dug in the footpath or roadway, as the case may be.

From these main cables, smaller cables are taken off, and lead direct into a building, or on to a distributing pole, and thence by open wire to the subscriber's house or office.

The conduit for the cables adopted by the Company where a large number of cables has to be handled, viz.:—the concrete block, has proved inexpensive, compared with other systems, and reliable. The blocks are made at the Company's own works, the process being as follows:—Portland cement, sharp sand and gravel gauged together, the finest quality of cement being used and tested by the usual tests by means of filling with Faijas machine, by spreading on glass plates and setting wet and dry, and by making briquettes. The concrete, after being turned over, is filled into steel moulds, and is rammed continuously during the filling. Strings of No. 8 galvanised wire are left in the mould to give extra cohesion to the concrete throughout its mass. The mould is taken to pieces, and the tubes slid out, leaving the complete concrete block with grooves for iron support bars, and conduit holes $3\frac{1}{16}$ inches in diameter.

The blocks are watered and matured for several months. It will be of interest to you to know that the first blocks manufactured in this country were made in Liverpool.

The blocks are made in sizes to take from three to thirty-six cables.

In laying the blocks, the necessary trench having been excavated, so as to allow of the blocks being laid at not less than 2 feet from the surface, great care, of course, has to be exercised to see that they are

level, especially as regards the cross section of the trench, and thus allow of the holes being in a true line and the joints being perfect.

After the ground has been prepared and the concrete bearers placed ready, the blocks are lowered by means of the legs into position. The joints are then covered with a neat cement, and prepared canvas coated with asphalt pitch, and finally with neat cement over the joint, and also the iron jointing bars, the whole being allowed to set before the mandril is put through to prove the work. Strength and stability is given by the iron rods of varying sizes, depending upon the size of the block, which are placed in the grooves at the sides and tops of the blocks, care being taken that they do not all finish on the one block, and also by the concrete bearers which are placed under each joint.

The pipes used, where less than three cables are required, are 3 inches spigot and socket cast iron, 9 feet long, and are manufactured by local firms. They are yarned and lead jointed and are laid with split bends, as circumstances require. For the convenience of running the cables and for jointing purposes, manholes are provided. These manholes are built of Staffordshire brindle brick 9-inch work, jointed in cement mortar one to two. They are formed in English bond, and have steel girders 5 inches by 4 inches to support the flags, which are 4 inches thick, and which form the cover. Iron covers, with body holes 2 feet square, are provided, with concrete or wood block filling.

The cables used in connection with the underground work are known as dry core. The conductors are of copper and are insulated by specially prepared paper wrapped round the conductors. Each wire is coloured, red or white, and each red and white is twisted together in pairs. Then each layer of pairs is twisted obliquely across the neighbouring pairs; all done with the object of preventing induction or overhearing.

The cables are made up into different sizes according to requirements, the largest containing 306 pairs. They are enclosed in a lead sheath. With a paper dielectric and air insulation it is needless to add that it is all important that the paper covering should not become damp, and to preserve the cable from the slightest humidity, or otherwise, it would have the effect of putting the wires in contact, and so cause trouble on the circuits. The cables are therefore hermetically sealed, the lead covering being continuous from one end of the cable to the other, whether other cables are teed on to the main cable or not. At the Exchange end and distributing end, where it is necessary to

connect up other types of conductor, a joint is made, called the Pot-head, as follows :—

The paper-covered wires are jointed to vulcanized indiarubber wires at the Exchange, and run to the testboard. A lead sleeve is slipped over the joints that have been made and wiped on to the main cable. The bottom of the sleeve is then packed with cotton wool to prevent the compound of pitch, which is poured in, getting to the paper covering. This compound sets hard and prevents any damp from entering the lead cable. A brass nozzle is inserted in the lead covering, so as to allow dry air being pumped through the cable to dry out any humidity and make the insulation of the wires perfect. The air is dried by being pumped through chambers containing chloride of calcium. The pump is driven by an electric motor of 1 H.P., and makes 100 strokes per minute, giving 21·8 cubic inches of air at each stroke, which is about sufficient to raise a pressure of 2½ atmospheres in a cable 3 miles long in an hour. When pumping dry air through a cable to raise the insulation through a defect, a vent is left open at the free end. In the case of a slight defect in the sealing of the cable, it will easily be discovered by forcing the dry air through, and the air issuing will take with it all dampness.

Extremely little trouble has been experienced with the cables after they have once been connected up.

Occasion arises sometimes where a cable has to be run overhead temporarily. A cable, known as an aerial dry core, is used, similar in construction to the underground cables, except in place of the lead sheath a rubber covering is used, which is again covered with hemp.

The cable is jointed at its terminals by means of the Pot-head, as already described. These cables were largely used as a temporary measure to carry the wires across the tramways routes after that regrettable accident in February, 1901, when, as a result of a combination of peculiar atmospheric conditions, the snow lodged on the open wires to such an extent that they gave way under the strain, falling across the trolley wires. It will probably be of interest to you to know that to prevent the possibility of an accident (though however unlikely) occurring again, and notwithstanding that the underground scheme in the ordinary course would have cleared the trolleys, the Company, at an expense the author does not care to be reminded of, had the whole of the open wires collected into the protected cables within six weeks, and the whole of these cables again taken down, and underground cables substituted, so that within a very short

period from the time the work was commenced, not a wire of any description belonging to the Company remained across the trolley tracks.

This work, though undoubtedly reflecting great credit on the Engineer and his assistants, could not have been carried out so expeditiously but for the valuable assistance received and readily given by the Liverpool Corporation through their chief officer and their assistants. The City Engineer, Electrical Engineer, and Surveyor have always given every assistance to the Company in carrying out the important telephone works, and the author is glad of this opportunity of acknowledging it.

A few figures in connection with the work provided and in hand for the telephone requirements of this city, will probably be of interest:—There are 386 distributing poles, each connected with the underground cables, from which the subscribers' lines are run overhead, and the number is being increased almost each day as the underground work is proceeded with. There are also 84 buildings in the city, which are supplied direct with underground cables, varying from 5 up to 80 subscribers in each. All the subscribers are being served with underground cables, and the work of transferring the overhead lines is well in hand, so that we have over 322,000 yards of duct, of which about half is filled with cable, the length of cable amounting to 183,000 yards. There are over 400 manholes.

While these extensive underground works have been progressing the Company have not been idle in making provision for the future development of the telephone in Liverpool in the switchrooms. The existing switchboards having been congested owing to the growth of orders in the immediate neighbourhood of the Town Hall, and also at some of the subsidiary Exchanges, it became necessary to open a relief Exchange. A piece of ground was bought in Great George Street, running right through to Rathbone Street, and upon this site has been built premises specially designed for a large Exchange. The Switchroom alone has a floor space of 9,000 feet, and will ultimately hold comfortably switchboards capable of accommodating 10,000 subscribers, and is one of the finest switchrooms in the Kingdom. The capacity of the other offices necessary in connection with the working of a large Exchange, such as test-rooms, power-rooms, stores, inspectors' and cloak-rooms, kitchen and dining-rooms, are all on the same liberal scale. In the operators' dining-rooms 150 operators can sit down to dinner at one time, if necessary.

At the end of the first portion of the paper, the author explained

how the underground cables were treated so as to allow of their being terminated on to the carbon lightning arrester and fuse strips. These strips serve the three-fold purpose of acting as a means whereby the outside or line wire is joined up to the inside or switchboard wire through the test-board, and as a lightning protector and also a fuse to protect the switchboard apparatus should by any means a current prejudicial to the apparatus get in contact with the subscriber's wire. In an underground telephone system the chances are very remote that either of these safeguards would ever be called into use, but with delicate and expensive switchboard apparatus no risk can be taken. The two line wires necessary for each subscriber's circuit are therefore brought on to the tabs of the heat coils strips, thence through the heat or sneak coil to the test strips. This sneak coil is actuated by any current above ·3 amperes, passing through the coil for a sufficient time, heating the bobbin and melting the solder, releasing a stud which allows the springs to fly back on to a contact, which is connected up to an indicator in the form of a lamp and a bell, thus informing the test-clerk that the fuse has gone and of its locality.

In the event of a line being struck by lightning the current would pass through the carbons, which are separated by mica, and discharge itself to earth, the frame of the strips being connected direct to the ground. From these fuse strips wires are run to the test jacks, which are simply springs so arranged that in their normal state they present an uninterrupted circuit, but by the insertion of a plug the test-clerk is enabled to test the inside or outside circuit as required. It should be mentioned that the subscribers' wires are brought in by the underground cables serving different areas, and consequently contain any subscriber's number that may be on the Exchange. By means of the cross connecting wires between the fuse strips and the test strips subscribers are placed in numerical order. From the test strips the wires are connected on to the distributing frame. The object of this frame is to provide the facility for distributing the work according to the traffic for each operator. This distributing board is a most important part of the equipment of a busy Exchange, as you will readily understand how changeable the traffic at an operator's position may be through change in the markets, style or business of firms, weather and many other causes, affecting the increase or decrease of traffic. From this frame a circuit is taken to the multiple or local jacks, a calling and clearing relay being in parallel. Now let us see what sort of apparatus is provided in the switchroom to enable the operator to deal with the calls received.

The boards are what are termed multiple boards, each section constructed to contain the full capacity, viz., 10,000, and fitted for three operators' positions, each operator attending to a certain number of these subscribers according to their traffic. From the slides shown on the screen you will see each operator, by this arrangement, while only attending to a few subscribers, will have within her reach the full capacity of the spring jacks on the switch-board. The wiring of these spring jacks has to be done with great care, the wires, which are soldered on to the connections, being confined to a very small space. There being eight panels or sections in each board the wires to each panel are brought out in different lengths, the length for the first panel being about 5 inches, the second panel $6\frac{3}{4}$ inches, and so on, increasing each panel by the width of the cable. The cable used for this purpose contains 63 wires, the conductors being tinned copper and silk covered. It is made up of 21 sets of three wires, 20 of these sets being used, and the other three wires being left spare for emergency: two wires in each circuit being for the lines and twisted together, the other being for the test circuits. To distinguish the wires, different colours are given to the outside covering of cotton to one of the wires in each set of three. This is known as the "A" line of the subscriber's circuit, the "B" line always being white, and the test wire a mixture of red and its corresponding "A" line colour. Variations of this cable are used for different purposes, containing 10 up to 84 wires. It is protected against damage from fire by having the outside covering served with fire-proof paint, and is also protected from damp by a lead-foil sheath. The subscriber's local or home jacks and lamps are taken direct to the distributing frame in the test-room by means of an 84-wire cable containing sets of 20 subscribers. On a subscriber ringing, the lamp will light, and the operator will insert the back cord of any pair of cords into the spring jack corresponding to the lamp, which action at the same time automatically puts the lamp out, and pulling over the lever corresponding will connect that subscriber to her telephone. On the subscriber giving the number and name of the Exchange required, the operator picks up the front cord, and if it is a subscriber on the same Exchange that is required, touches the brass ring encircling the jack. If the subscriber should be connected elsewhere the operator would receive a loud click in the telephone, which immediately tells her that the subscriber asked for is engaged. If it was not engaged no click would be received, and the plug would then be inserted, the lever reversed, thereby ringing

the subscriber, and the key allowed to spring back to its normal position on the called subscriber replying, and the two subscribers being put into communication. The author would particularly draw your attention to the rapidity with which it is possible for an operator to find out whether the particular subscriber asked for is engaged; it is a matter of seconds only.

On the finish of the conversation both subscribers should ring off. Either doing so would have the effect of lighting a lamp connected with the pair of cords used, and thus notify to the operator that the subscribers have finished, and she immediately withdraws the plugs, which are then ready for another call. Should the subscriber wanted be in another Exchange the operator goes on to a special service or call wire to the Exchange upon which the subscriber wanted is connected, and asks for the number required, and is given a junction to the Exchange; at the same time is connected to the subscriber asked for and rings right through to him. If he happened to be engaged the junction would be connected to what is called the "Busy-back," which gives an intermittent buzz on the line, telling the operator at once that the line is engaged. The operations necessary in connecting a subscriber, no doubt, sound simple enough, but the apparatus and connections involved are by no means so simple, as you will see by diagrams shown on the screen. From the diagrams and the samples of apparatus shown here on the table you will see that much ingenuity is called into play to accomplish the necessary results. The author ventures to think that modern telephone apparatus in design and finish, and for obtaining the very best results in the smallest space, will hold its own with any other electrical apparatus. The author will now explain briefly the line circuit, showing what apparatus is brought into use upon a subscriber ringing up the Exchange.

On the subscriber ringing, a current from his telephone would pass through the contacts of what is known as a cut-off relay to earth on the "B" line and through the resistance "R" on the "A" line through the line relay to earth. This completes the circuit, and in doing so, actuates the line relay, which; in turn, causes a current to flow from the pilot relay (which lights a pilot lamp) through the line relay and lamp in shunt, and consequently keeping the calling or line lamps alight. The pilot relay also rings into play the night bell relay used at night time when there would only be a few calls, a small switch cutting this bell off when not required. On the operator inserting the answering plug in the spring jack a current from the cord circuit,

which will be explained next, flows along the test wire through the cut off relay to earth, at the same time causing the tongues of the cut-off relay to break the earth of the " B " line of the circuit, and cuts the calling lamp off. The instrument or cord circuit and the apparatus brought into use when the operator answers is somewhat more complicated. From the diagrams of the connections shown on the screen you will see that each operator is provided with a key which enables her to answer the subscriber and also to ring up the subscriber wanted, a pair of cords with 3-point plugs attached, a clearing ray and lamp to notify the operator when the subscriber has finished on ringing off, and the pilot lamp and relay to notify the supervisors as well as the operators that one of the 17 clearing lamps is glowing and giving the signal to clear, and also, of course, the operator's telephone instrument. On the operator receiving a call she inserts the plug into the local jack. This allows the current to flow through the 250 ohms resistance to the frame of the plug and thence to the cut-off relay, automatically keeping the line relay and lamp of this subscriber out of circuit, and in consequence the lamp ceases to glow. The operator then pulls forward the lever of the key to what is known as the listening position, and on ascertaining the number required, tests that number to find out if engaged or not, as explained previously. If the number is engaged, the circuit would be, starting from the battery to earth, through the 250 ohms resistance, through the test wire on the jacks to the frame of the plug already connected in the jack on a different board of the subscriber wanted, through the tips of the plug the operator was testing with, then through the listening key and induction coil and receiver to earth, thus completing the circuit. If disengaged, on the operator testing the line, the circuit would be incomplete and no click heard. In the latter case the operator would put the plug in the jack and by pressing the key backwards would connect the generator circuit (which has a vibrator in series to notify the operator that the generator is ringing satisfactorily). Directly the operator leaves go of the lever it automatically springs back to the centre position, at the same time placing the two subscribers in connection and with clearing relay across the line.

On either subscriber ringing off the clearing lamp glows owing to the armature of the relay being retained, and keeping the clearing lamp alight, until the operator breaks the circuit by bringing the lever of the key forward. The outgoing junction circuit worked on the call wire system is more simple. On the operator requiring a subscriber on another Exchange, and given a junction line by the call wire

operator, she inserts a plug into the jack, which automatically cuts off the clearing current on that junction by the armature of the relay being held down, until the plug is withdrawn, thus releasing the armature and sending out a current on both lines which actuates a relay at the distant end of the junction, and lights the clearing signal lamp. You will note that special provision is made for the supervision, by means of pilot or supervisory lamps, which enable the switchroom manager and supervisors to at once notice if an operator is carrying out her duties properly. All the lamps are worked on 24 volt circuit, and each bank of 80 line lamps is protected by a fuse in the event of a short circuit. Should a lamp fail a pilot lamp in connection with this particular 80 will light. The fuses are collected in a fuse cabinet and are provided as follows :—

For the calling, and clearing lamps, conductor of the cord, and on the junction circuits.

To protect the operator's transmitter, a one ampere fuse is placed in each side of the circuit.

The lamps shown at the top of the fuse cabinet are 75 volt lamps. These are used in connection with the ringing circuit of each operator's position, and glow on a short circuit occurring Should the electrician not notice at once that one was glowing, the heat generated would cause a sneak coil to act, which in turn would light a lamp on the particular operator's position where the fault had occurred.

The author now comes to the power plant provided for supplying the necessary current for the lamps, operators' instruments, and ringing current to call the subscribers. It would probably be a revelation to most of you to see what is necessary in this respect in modern telephony. Accumulators of the chloride 1-inch plate type in lead troughs are used, each accumulator having a capacity of 800 ampere hours. These accumulators are charged by means of a dynamo having an output of 6 kilowatts, viz. : 200 amperes 30 volts. The dynamo is run by a 12 H.P. gas engine, Crossley's "Otto," single fly-wheel, link belting being used. A motor generator is also provided, which is run from the Corporation mains. It is a multipolar type machine, the motor taking 230 volts at 11 amperes, the output being 65 amperes at 32 volts. This machine is used as a stand-by, the accumulators being placed across the motor generator as a regulator. The ringing current is provided by means of a dynamotor, which is driven from the Corporation mains, taking a current of ·5 amperes to drive as a motor, the output being 75 volts alternating, and can give a current of 2 amperes at a speed of 1,000 revolutions per minute. The other

dynamotor is worked from the accumulator cells, taking a current of 7 amperes to drive, and as a motor giving an alternating current of 75 volts, the speed at full load being 700 revolutions per minute. This machine can give an alternating current of 2 amperes. Fitted on these machines is an arrangement of wheels with insulated segments for the purpose of a "busy back." An interrupted current is produced at a very high frequency, causing a buzz when a line is connected, as explained previously, for the purpose of giving the subscriber and the operator the engaged test. An extra machine is provided, and is run off the 24 volt circuit from the accumulators: in other respects it is the same.

The power board is of marble, and contains the apparatus and switches for the following purposes:—

Switches for the charging and discharging of the accumulators either from the dynamo, or the motor generator.

Switches for the dynamotors or ringing machines.

Voltmeters taking the readings of the cells individually or collectively.

An ammeter to test the amount of currents flowing in all the circuits on the system. In connection with the charging switches is an over-load and under-load switch, in conjunction with a polarized relay. This is used to protect the cells by cutting them out of the charging circuit in the event of the voltage dropping. Should the charging current exceed the limit, the switch would act and cut the cells out of circuit.

It may be mentioned that provision has been made in all the apparatus to convert the system into what is known as the "Central Battery System" with very slight alteration. This system provides for the current to be supplied from one main battery at the Exchange, not only to work the apparatus in the switchroom, but for the current required for the working of a subscriber's instrument, and so do away with local batteries, and also the necessity for a subscriber to turn the handle on his instrument in order to ring up. It was not thought advisable, owing to the number of Exchanges at present in Liverpool and Birkenhead, and the time it would take to carry out the complete alteration, to change the existing method of ringing up.

In conclusion, the author would be very pleased should any of the members of the Society wish to see the board, which he has endeavoured to describe — to take them over the switchroom, and explain more fully the very many interesting matters of its construction.

DISCUSSION.

Mr. Cooper

Mr. F. E. Cooper said—The point which particularly interests me in the paper is that of the digging up of the streets and footways, as the Roads Department has to follow the Telephone Company up and make good what damage they unavoidably do. Perhaps it may interest some of the members to know the magnitude of the work involved in following up the various Companies in Liverpool, and I find that we had over 85 miles of trenches to re-instate during one period of twelve months after the Telephone, Electric Light and other Authorities had done their worst with our paving. The author gives thanks to the City Engineer, Electrical Engineer and Surveyor for their assistance, and, for my part, I will say this for the Telephone Company, that while they appear to be labouring under very great difficulties, I think they do their best to mutilate the streets as little as possible. I think it is a matter which ought not to be lost sight of, that the Telephone Company have been the pioneers of the subway system in Liverpool. I should say it has paid them to adopt this system, and it is a matter which will have to be looked forward to, at any rate in many of the congested portions of the city, as to whether or not some general system of subways will not have to be adopted with a view to prevent the continual pulling up of the streets.

Mr. Priest

Mr. F. E. Priest said—With regard to the destruction of the lead casing of the cables in Fulwood Park, I do not know if there is anything peculiar in the natural soil, and I imagine that the effect is produced by some importation. Whether the site is within reach of the Garston Gas Works I cannot say, but if it is, I should think very probably the cables have been laid where gas lime has been dumped. The effect of lime on lead has often been remarked, and gas lime is a material that is disposed of carelessly in many places. So many lead pipes have been damaged from contact with lime that in all probability that is the cause in the case in question. It may be, however, that some other chemical refuse has been put there.

Mr. Hirst

Mr. JOHN A. HIRST said—The arrangement of the glow-lamps on the switchboard is not quite clear to me. I understand that a lamp glows at the bottom of the board when a call is made and as soon as the operator inserts the plug another lamp lights. I should like to know the function of the second lamp.

Mr. White

Mr. J. WALWYN WHITE said—I should be pleased if the author would explain how the buzzing noise is caused which we hear very often. We have some long-distance calls every day—it is not so bad latterly—but, until a short time ago, there was such a fearful buzzing sound that one could scarcely hear a word that was said.

Another point I should like to mention is the noise made by the wires over the roofs. It is sometimes so great that it is impossible to sleep at nights, owing, I suppose, to the Æolian harp action of the wires.

Mr. Fozzard

Mr. W. C. FOZZARD said—I would like to ask the author whether the concrete blocks are laid horizontal or with a fall.

If any condensation takes place in the conduits, if such is the case, what provision is made for taking the water away?

Mr. Maxwell

Mr. M. H. MAXWELL, Jun., said—I would ask the author how it is that on many occasions another subscriber can ring one up and yet it is absolutely impossible for one to get into communication with anyone else?

Mr. Wilson

Mr. H. W. WILSON said—The point that occurs to me is this, that in spite of the great perfection of the switchboard arrangements at the Exchange there still appears to be a difficulty in getting a reply. I do not think that the Liverpool system is quite as bad in this respect as in other towns, but in Manchester you may try to get into communication with the Exchange for upwards of half an hour and get no reply whatever.

As regards the damage done to the lead covering of the cable in Fulwood Park, I understand, in the early days, there used to be a large copper smelting works in the South end. I do not know whether any refuse has been taken from these works to Fulwood Park, but I think this is more likely than that the damage was caused by lime from the Garston Gas Works. Moreover, the houses in Fulwood Park were probably built before the Garston Gas Works were erected.

Mr. Miller

The President, Mr. T. L. MILLER, said—Before calling upon the author to reply I should like to make one or two remarks with regard to matters which have been mentioned during the discussion.

First, as to the lead covered cables. I do not know that the state of things described is peculiar to Fulwood Park, as when the Liverpool

electricity supply undertaking was first inaugurated lead covered cables were largely used for making service connections, and these had all to be renewed owing to the pitting and corrosion of the lead, which was due very largely to the presence of salts in the earth. At Bootle, again, I had a similar experience, as although the lead covered cables were laid in earthenware conduit and run in solid with bitumen, there was in a number of instances a very considerable amount of damage done to the cables, due, possibly, to slight leakages acting in conjunction with the salts in the earth. In one case, in particular, on taking out a damaged cable, I noticed a white deposit in the bitumen, which smelt strongly of chlorine. On having this analysed it was found to be due to the presence of free salt either in the salt glaze of the conduit, or more likely to the presence of salts in the surrounding earth. Mr. Miller

Dealing with the paper, there is one matter which I think must have particularly struck the members on looking at the photographs of the old and new Exchanges, and that is, the great advance that has been made since the days when the old Exchange was constructed to the practice of the present time as exemplified in the present Royal Exchange. In this connection you will have noticed that in the old Exchange the framework for carrying the various switchboards are very largely built of wood, whereas in the new Exchange they are built almost entirely of iron, and are made as fire-proof as it appears possible to make them. You will have noticed, also, the different way in which the cables are carried about. In the old Exchange the cables appear to be all in confusion, whereas, in the new Exchange they are brought into a compact mass and carried from point to point along iron gratings, thus exposing all the cables to view and minimising the risk of danger from fire. This, I think, is one of the greatest improvements in the constructional work.

The author has kindly brought a very large number of samples of apparatus used in telephone work, an inspection of which cannot fail to be of interest to the members of the Society. In particular, I would draw attention to the sneak coil device for cutting out the circuit in the event of a heavy current passing along the wires. This, I think, is one of the most beautiful little pieces of apparatus to be found in the works, and will well repay further investigation.

Mr. Cooper, in his remarks, referred to the question of subways. Well, subways are very good for many purposes, but it must not be forgotten that when large numbers of service connections are required to houses or premises along the line of the subway the

Mr. Miller expense of such connections becomes very much greater indeed than the present method, although, of course, economy is effected in other directions.

Mr. Hidden Mr. HIDDEN, in reply, said—I am very much obliged to you for the way in which you have received this paper, and I can only repeat what I have said—that I shall be pleased to explain the subject more fully to those members of the Society who care to visit the Exchange.

Mr. Miller mentioned the subject of fire precautions. These precautions, in a large Exchange where we have 10,000 subscribers—all busy people—using the telephone, are most important, because an outbreak of fire, in a very short time, would probably mean a disconnection of the best part of those subscribers.

The discussion that has taken place with regard to the lead covered cables has been most interesting, and I am rather inclined to think that chemical refuse has been the cause of the trouble. The latter may have came from the pottery works which I understand used to be in existence many years ago in the neighbourhood of Fulwood Park. This will be 40 years ago, and probably before the erection of the Garston Gas Works.

With regard to Mr. Cooper's remarks as to subways, I know that the Company would only be too delighted if subways had been provided in Liverpool. There are many difficulties, of course, to be surmounted before they could be adopted, and, on the other hand, concrete blocks are comparatively easy of access.

Mr. Hirst asks a question as to the calling circuit. When a subscriber calls, he turns the handle of his magneto which actuates a relay. That lights a lamp under his local jack. When the operator inserts the plug it puts the subscriber's lamp out that was alight, but in the meantime there is the pilot lamp lighted. There is another lamp which, when the subscriber rings off, lights, and also all these lamps are in connection with the supervisory lamp, which keeps alight until they are all clear. This system has a great advantage over the old system of indicator flaps.

With regard to Mr. White's remark as to the buzzing noise, this is probably due to the lines being out of balance owing to dampness and wet.

With regard to noisy wires over roofs, that, of course, is bound to happen occasionally. The temperature affects the wires and lightens them, but on being reported it is easily rectified.

Mr. Fozzard asked whether the concrete blocks were laid straight or with a fall for draining purposes. Well, I do not think we consider

that at all. We simply lay them where we can get them. Liverpool is full of gas and water pipes, and you would be surprised if you saw the roads when opened how we ever got the cables in at all. Mr. Hidden

Mr. Maxwell asked, how it is possible for a subscriber to be rung up and yet that subscriber is unable to get into communication with the Exchange. The reason is that the connections made are on circuits. When a subscriber rings up, he is attended to by one of the operators on the local jacks, but he can be rung up from any of the positions in the room. There are 80 or 90 positions, and any of the operators can obtain for themselves any one of the subscribers. On a subscriber ringing up, he only lights his own lamp, and the lamp may be out of order or there are very many other reasons which may cause delay.

Mr. Wilson mentions about not being able to get the operator. I am afraid this is not the time or place to go into these matters. There are many reasons why it may happen. So long as you have manual operators, and until you have mechanical operators, I am afraid you will have some trouble.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

FOURTH MEETING—16TH DECEMBER, 1903.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E., PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. R. S. CRAWFORD and H. G. MCHAFFIE, as *Members*.

POLYPHASE MACHINERY AND WORKING.

BY H. W. WILSON, A.M.I.E.E.

WHEN the author undertook to read a paper before this Society upon Polyphase Machinery and Working, he did not fully realise the magnitude of the task undertaken, and, therefore, if any of the points raised seemed to be dealt with in an incomplete manner, he trusts you will regard this as being due to the fact that it is impossible in a paper of this length to deal satisfactorily with more than a very small proportion of the questions that arise. As, also, during the coming session papers are being read upon Induction Motors, Voltage Regulation in Alternating Current Plants, Electrical Transmission from Water Powers, and the Design of Electrical Machinery, the author proposes to only touch upon these points in the briefest possible manner, as many of the details concerning them will be fully dealt with by the gentlemen reading these papers.

It is well known that the great developments in electrical power transmission plants that have taken place during the last 15 or 20 years constitute one of the most notable modern developments of engineering, but as this is not purely an electrical society the author may be pardoned if he gives a very short historical account of the development of electrical power transmission during this period.

Many of those present will, no doubt, remember the beginning of heavy electrical engineering and will recall the time when that which has often been called "the battle of the systems" raged with great bitterness, and for some years it was very doubtful to the minds of many engineers whether a direct current or a single phase alternating system was preferable. At that time the limitations and advantages of both systems were imperfectly understood, and the champions of either system could not see anything good in the other. In those days, of course, electricity was used almost exclusively for lighting purposes, and for this work the simplicity and comparative cheapness of a single phase system gave it a considerable advantage. Single phase plants of fair size were laid down, the most notable being that at Deptford, designed and installed by Mr. Ferranti. As time went on, however, the advantages of electrical transmission for power purposes became evident, largely due to the improvements in the direct current motor, direct current installations had so many points in their favour that in most municipal installations such plants were generally put down. The great weakness of a single phase system was the lack of a satisfactory self-starting motor. In more recent years the phenomenal developments of electric traction, for which purpose direct current is in nearly all cases used, also tended in municipal installations of medium size to encourage direct current systems of generation and distribution. As experience widened, however, and the possibilities of alternating current working began to be realized, it became evident that for long distance transmission a polyphase system was inevitable. Some historical long-distance high voltage direct current plants, mostly of small size, were put down, notably in Switzerland, but about 1891 two- and three-phase alternating current plants with synchronous motor equipments began to come into use. It was not, however, until the invention of the alternating current induction motor, about 1891, that polyphase working received its first great impetus. The best known names in connection with the invention and development of the induction motor are those of Nikola Tesla, Von-Dolivo-Dobrowolsky and C. E. L. Brown. In fact it may be said that it is to these men that the main development of alternating current working became possible.

It will, perhaps, be most convenient to deal briefly with the possibilities of polyphase systems. These installations may be regarded as falling naturally into two main classes :—

(1) Alternating current plants with direct current converting equipments for distributing the energy.

(2) Purely alternating current installations where both generation and distribution is on the alternating current system.

Either of these classes may use high or low voltages in their primary generating plant according to the transmission conditions. Equipments under the first heading are typical of the ordinary American long-distance transmissions from water power stations, the current being used mainly for operating tramways or light railways, or for the plants now being put down in the large cities, both of this country and the Continent, where the original small direct current stations having been outgrown, large power houses are erected on the outskirts of the cities and high tension alternating current taken to sub-stations in the towns, and these converted to direct current for supplying the traction and lighting feeders. Notable examples of such equipments are to be found in this city (Liverpool), Manchester, Glasgow and Berlin.

Under the second class are to be found the factory and mining plants now becoming fairly general, wherein only polyphase currents are used and in the town installations without a traction load where alternating current is distributed for lighting and power.

Before passing on, it will be convenient to summarize very briefly the arguments for and against polyphase and direct current plants for general lighting and power purposes. It may be taken as granted that just at present direct current has distinct advantage for tramway work, although it seems possible that this is a condition of things which will be modified in the fairly near future.

For lighting and power work, however, it will be usually admitted by those having experience of both systems that the operation of one is as satisfactory as that of the other, given properly designed plants. But with regard to those elements in which there is a difference of opinion, are the reasons for the use of direct current quite strong enough to justify the increased expense and complications of the converting apparatus? To answer this, it will be well to consider the question from two different standpoints:—

(1) In the utilisation of electrical energy, has direct current any advantages over alternating current?

(2) When energy is generated as alternating current, what disadvantages are envolved in utilising it as direct current?

Taking the first of these, let us consider the ordinary classes of service and the means of providing for them. Incandescent lighting may be considered as indifferent to the character of current, whether it is alternating or direct, provided the frequency be sufficiently high to prevent flickering. Arc lighting is most extensively carried on by

enclosed arc lamps, which are satisfactorily operated from direct current circuits and also from 50 cycle alternating current circuits, so that within this range there are no very great reasons for specially choosing one current or the other as far as arc lamps are concerned.

In discussing motor service, it is not the author's intention to enter into a controversy as to the relative merits of alternating and direct current machines. Both kinds of motors are now in extensive use for nearly every kind of service. The induction motor is notable in having no commutator, and can be built very substantially, and is specially adapted for any service where it is likely to be subjected to rough handling. It is especially fitted for general distribution of power in all sorts of places, as such motors require a minimum of attention.

For constant speed work, probably no one will question the superiority of the alternating current motor from the standpoint of the man who uses the motor and pays for repairs. Any objections which may be brought forward, will probably be urged on account of reasons applying to the supply system, such as power factor, starting current, and voltage regulation. These items may be provided for, by care in the designing of the system, and can hardly be regarded as legitimate objections to the use of alternating current motors.

For variable-speed work the conditions are somewhat different. The fundamental difference is due to the fact that although there is a close correspondence between the induction motor and direct current shunt wound motor with constant field excitation, the alternating current motor does not have an exact analogue to the direct-current series motor. It follows, therefore, that direct-current motors cannot be exactly duplicated by induction motors, and the results which may be desired must often be obtained in a way different from the methods employed with direct-current motors.

From the above summary, it appears that all the important classes of service for which current from a central station is used, may be successfully undertaken either by direct current, or alternating current, sometimes equally well, sometimes with the advantage on one side, and sometimes with the advantage on the other side. The most important difference is probably in the case of variable-speed motors, and the importance of this will depend quite largely on the proportion of this kind of service. Although the alternating-current motor cannot exactly replace the direct-current machine, so that there may be some inconvenience in changing from one system to the other, yet, when a new plant is being laid out, it is probable that the cases

are very rare in which it would not, on the whole, be practicable to utilise either alternating-current motors, or direct-current motors.

To consider next the apparatus employed for producing and distributing current, the elements in the two systems may be stated as follows :—

ALTERNATING CURRENT ONLY.

Alternators. Switchboards. Primary Mains.
Sub-stations with Transformers.—Distributing Circuits.

ALTERNATING AND DIRECT CURRENT.

Alternators. Switchboards. Primary Mains.

Sub-stations with—

Switchboards. Transformers. Switchboards. Rotary Converters.	or	Switchboards and Motor Generators.

Distributing Circuits.

Comparing these in detail, the generating station in general will be substantially the same for the two systems, although a higher frequency will usually be employed, if there is little or no conversion to direct current. The primary feeding system will also be substantially the same in the two cases, differing, however, in the number of points at which the transformation is made to the low voltage, and the distributing system is supplied with current.

The sub-stations for conversion into direct current constitute the great difference between the two systems. Sub-stations with converting apparatus are expensive to instal and to operate. The cost of the sub-stations naturally makes it desirable to have as few as possible; hence, they are located at as great a distance apart as the distributing circuits will permit.

The cost of distributing circuits for direct current is, therefore, very much greater than for the low tension alternating-current circuits, to which current is supplied from a large number of transforming points, since the alternating-current circuits are comparatively short, and the cost of copper is thence greatly reduced. This effects a saving not only in the cost of conductors themselves, but also in subways and ducts, which are often limited in capacity and high in cost.

Leaving till a little later the question of sub-station connecting equipment, it becomes necessary to notice the general construction of the main alternating-current generators.

These may be divided into three types, as examples of each kind are to be found running. They are :—

(1) Revolving Armature.

(2) Revolving Field.

(3) Inductor Alternator.

Class (1) is now used only for small units or sometimes for larger low voltage machines ; class (2) is that used for all other cases ; class (3) has ceased to be manufactured on account of its bad voltage regulation on inductive loads and the very small clearances required. The author is showing illustrations of each class of machine, but would point out that the now general use of revolving field alternators is on account of the fact that with the fixed armature all the high voltage windings are stationary and therefore subject to very little vibration liable to damage the insulation, and also to the large fly-wheel effect to be obtained from the revolving field magnet system, which helps to overcome the cyclical variation of rotary speed due to reciprocating engine. This is an exceedingly important point when running alternators in parallel. Inductor alternators have both fixed armatures and magnet systems, and a revolving ring carrying symmetrically spaced masses of iron produces variation of the magnetic flux between the armature and the poles faces, thus inducing a current.

A point worthy of note is the gradual settling down to standards of the periodicities and voltages of alternating-current plants, concerning which matters, there have been great differences of opinion in the past.

In the States they use a periodicity of 25 cycles per second for rotary converter tramway sub-station equipments, 40 cycles per second for mixed traction, lighting and power, and 60 cycles for lighting and power only. Lighting, particularly arc-lighting, is best above 40 cycles. The standard voltages are 220, 440, 550, 2,080, 6,600, 10,000 and upwards.

In Europe, generally, the most common periodicity is 50 cycles, which is a general standard in this country for all purposes, although for purely traction work 25 cycles would be used. 6,600 volts is the pressure used for the high tension transmission mains of a great many municipal three-phase plants, including that of Liverpool.

Before proceeding with the discussion of sub-station plant it will possibly be a convenience if a very brief outline is given of the principal apparatus employed therein. It is assumed, in the first place, that the principle of the ordinary single phase static transformer is familiar to all present, and the author would say, that the facts underlying the transformation of polyphase currents to currents at a higher or

lower pressure differ little from those involved in the transformation of single phase currents. The law which states that the ratio $E1/E2$ between the induced electromotive forces in the primary and secondary is equal to the ratio between the number of windings $S1/S2$ holds good in the case of all coils wound upon the same magnetic circuit ; and the laws relating to the losses in the copper and iron apply to polyphase and single-phase currents alike. However, the transformation of polyphase currents is not infrequently carried out by means of ordinary single phase transformers, one being placed in each of the polyphase circuits suitably connected up. Sometimes, however, it is more convenient to have one transformer for all the circuits, and a saving in the cost of materials can thereby be effected, though the labour cost is higher. For this reason American practice is generally to use single-phase transformers, and continental practice to use polyphase, on account of the high cost of labour in the States.

With respect to synchronous and asynchronous (or induction) motors: the difference between these machines may be stated as follows:—

A synchronous motor is practically an ordinary alternating-current generator driven as a motor. In this respect an alternator behaves like a direct current machine with shunt excitation. The machine requires to be supplied with direct current for exciting the field magnet system and with alternating current to be converted into mechanical energy. The speed of a synchronous motor depends entirely upon the number of poles and the frequency of the circuit, and by varying the excitation of the magnetic system a varying power factor can be obtained. It is, indeed, possible, by over-exciting a synchronous motor to obtain a power factor equal to unity, and for this reason synchronous motors are often used on a circuit from which induction motors are driven to help to level up the power factor of the entire system. The weak feature of a synchronous motor is, that in order to start it, it must be run up to the speed of synchronism from some external source and then switched on to the supply circuit. This fact militates greatly against its employment except in special circumstances.

A polyphase induction motor has the distinct advantage over the synchronous machine of being self-starting. Speaking generally, an induction motor may be regarded as a transformer with two main elements: the primary, which is directly magnetised by the current taken from the power circuit, and the secondary, in which low potential currents are induced by the action of the primary. The revolving element may be either the primary or the secondary, and in order to

avoid the use of the terms "armature" and "field magnets" in connection with these machines, the revolving part is spoken of as the rotor and the fixed element as the stator. The appearance of induction motors is doubtless familiar to all of you, and the main advantage of the machines is their self-starting property. As previously pointed out, very strong mechanical construction is possible, and in many cases all moving contacts with the possibility of sparking can be avoided. The weakest feature of the induction motor is its power factor, and concerning this it may be said: that all induction motors give rise to a lagging current, this increases the current taken by the motor and causes the volt-ampere input to exceed the actual power of watts input. The ratio of the watts to the volt-amperes supplied is called the power factor. The lagging or idle current being out of phase with the E.M.F., no actual loss of energy is represented beyond that absorbed in heating the conductors, but at light loads the power factor has an appreciable effect on the efficiency. A low power factor requires greater current carrying capacity in the cables and an increase in the size of the generators on the station, but not an increase in the size of the prime mover. A very bad power factor will considerably affect the voltage regulation on the circuit. The rotary effect in an induction motor is produced by the fact that when a polyphase current (that is, alternating currents out of phase with each other), is taken through the different windings of the primary, which are suitably placed, a rotating magnetic field is produced, and this acting upon the secondary induces currents in it which, combined with the magnetic field produces a torque. As the load upon the motor increases, to maintain rotation the torque has also to be increased, and this manifestly necessitates a slight drop of speed. At no load the synchronous speed of the motor should be the same as that of the generator, but at full load a drop of speed of something like 4 or 5 per cent. will be manifest.

Seeing that a paper is to be read upon induction motors the author does not propose to deal at length with any of the details of construction, but will merely say that two types are commonly found:—the first, the induction motor with squirrel cage rotor, in which machine current is merely supplied to the fixed primary or stator, the rotor being a mass of iron laminations with fairly heavy copper bars passing through slots or tunnels in the periphery and short-circuited together at the ends by means of copper rings or other suitable devices. This machine is, of course, absolutely sparkless, and can be used in situations where very limited attention is given; its main disadvantage is the large starting

current taken. In the second type of motor the rotor is wound similarly to the stator and the current is conveyed to the rotor through slip rings with suitable brushes. A rheostat of some kind is then used for starting the motor up, or, in some cases, for speed regulation, but speed regulation of induction motors whilst possible is not economical. The starting current of slip-ring motors is, however, very much smaller than that of squirrel cage motors. It may be a convenience to some to give a formula for obtaining the full load current per phase in an induction motor, and this can be easily calculated as follows :—

$$\frac{\text{H.P.} \times 746 \times 100 \times 100.}{\text{Per Cent. Power Factor} \times \text{P.C. Efficiency} \times {}^{*}\text{Constant} \times \text{Voltage.}}$$

*Constant = 1·73 for Three-phase.
" = 2· for Two-phase.

The current in the middle wire of a two-phase three-wire system may be determined by multiplying the result obtained from formula by 1·41.

The no-load speed in revolutions per minute may be obtained by dividing the number of alternations per minute by the number of pairs of poles.

The other important machine to be considered in discussing sub-station equipments is the rotary converter, which is very largely employed in the States and abroad. A rotary converter is, speaking generally, a continuous current generator with symmetrical points on the armature winding tapped off to slip rings carried on the spindle of the machine on the side away from the commutator. A rotary converter can either be used for transforming from alternating current into direct current, thus working as a synchronous motor and a direct current generator, or it can be used in the opposite way, working as a direct-current motor and an alternating-current generator. Both kinds have been successfully used. Both the alternating and the direct currents are flowing in the same winding, and since one is a motor and one a generator current they will flow in opposition, or better still, only their resultant will flow. A rotary converter does not require any external excitation, being always self-excited, and it may be either shunt or compound wound. On account of the inherent features of the machine the output of the rotary converter as a converter is considerably greater than if it were used as a direct current generator. The capacity ratios for the output of a converter with the same C^2R loss in the armature that there would be if the converter were run as a continuous current generator are as follows :—

Continuous Current Generator ...	100	per cent.
Single-phase Converter	85	"
Two-phase Converter	164	"
Three-phase Converter	134	"
Six-phase Converter	196	"

These ratios vary slightly, of course, according to the details of construction, but may be taken as a fair average. Another noticeable point in connection with the machine is that the ratio of the alternating-current voltage to the direct current voltage is fairly constant from no load to full load.

The figures may be taken approximately as follows :—

	No load ratios of Potential.	
Continuous	100·	per cent.
Single-phase	71·5	"
Two-phase	71·5	"
Three-phase	61·	"
Six-phase	60·	"

The relative values of the continuous current, and the alternating current in the leads of a loaded converter, not considering the internal losses, are usually as follows :—

	Relative Values of Current.	
Continuous	100	per cent.
Single-phase	135	"
Two-phase	67·5	"
Three-phase	92·5	"
Six-phase	45·5	"

These values are true only for non-inductive alternating current of sine way form. If the alternating current is at all inductive, either leading or lagging, the alternating current values should be divided by the power factor to give the true ratio. Polyphase converters with non-inductive loads have practically no armature reaction, and, therefore, no shifting of the non-sparking point. The brushes may be set almost exactly on the neutral point, and need not be moved for changes in load, or direction of rotation, as in a generator.

We now come to the question of sub-station equipment, the foregoing remarks having outlined the various types of machinery used. Considering the general case applicable to large towns, the polyphase current will be sent from the distant power house over the high tension mains, arriving usually at a pressure of between 5,000 and 10,000 volts. The work to be done comprises the conversion of

the energy from this form to that of direct current of about 500 or 550 volts for traction purposes, or 2 × 220, or 250 volts for feeding the lighting network.

There are three different classes of equipment which can be used for this conversion, and they are: induction motor-generator; synchronous motor-generator, or rotary converter equipments. As will be at once apparent from the author's previous remarks, the first-named sub-station is the simplest to equip, to start up and run. Almost invariably when the units are anything like a respectable size, the high tension polyphase currents can be led directly into the induction motors, thus doing away with any transformers, and requiring only simple switch gear. No starting arrangements are required beyond a simple rotor resistance, which can be cut out gradually, and which frequently takes the form of a liquid resistance. As no synchronising is required, the starting up can be done by a comparatively unskilled man. The induction motor may be directly coupled to either one or two direct-current generators, and for feeding a three-wire system the latter arrangement is frequently used, such generators being, of course, each half the capacity of the motor. The voltage regulation on the direct current side is effected by a shunt regulator in the usual way, the direct current voltage therefore being entirely independent of fluctuations on the alternating-current side. The greatest drawback to induction motor sub-stations is their low power factor.

With a synchronous motor-generator sub-station, synchronous polyphase motors working at the line pressure take the place of the induction motors, and, generally speaking, the motors would be of the revolving field type, very frequently with small exciters carried on the main shaft. The equipment of such a station is more complicated as regards its switch gear than an induction motor sub-station, owing to the fact that the motors have to be brought up to speed and then synchronised on to the line. The starting of the motor-generator sets may be effected in various ways, but by far the best is to start them from the direct-current side. The direct-current may be obtained from the low tension network, and the machines run up to speed, the voltage of the synchronous motor properly adjusted, and the machine switched on to the alternating-current side. The combination will then start to deliver power to the direct-current mains. In a fairly large synchronous motor sub-station an induction motor generator set is often provided to act as a balancer, and to provide direct-current for starting up the synchronous motor sets in the event of the direct-current network being dead.

The main advantages of a synchronous motor generator sub-station are the absolutely constant speed of the motor, and the high power factor. The remarks concerning direct-current voltage regulation of induction motor sets applies to synchronous motor sets also.

When we come to rotary converter sub-stations, a considerably more complicated state of things exists. In the first place, it will be at once apparent from the figures previously given, that as the direct-current bears a fixed ratio to the alternating-current it is impossible to supply the alternating-current side of the machine with the full line pressure when high tension transmission is being used. It therefore becomes necessary to provide transformers to bring down the voltage to such a value that the ratio of transformation will ensure correct pressure being supplied to the direct-current feeders. The arrangements of the transformers are various, according as two, three, or six-phase converters are being used. A six-phase converter is worked from a three-phase circuit, by means of special connections to the secondaries of the transformers, and it is used on account of the larger output obtainable from a given machine, and better synchronising power. Six-phase converters are, therefore, very frequently used where large units are installed.

The methods adopted for starting up a rotary are various, the simplest probably being to start it up as a direct-current machine in the same way as a synchronous motor-generator set. The next best arrangement is by means of an induction motor directly coupled to the shaft of the rotary, whilst the third and last method available, consists in starting from the alternating-current side with the field open. This method, whilst fairly convenient on low periodicities, is not advantageous on high periodicities. The power factor of rotary converters can be varied similarly to that of synchronous motors by varying the excitation, and the machines are practically on an equality in this respect.

The voltage regulation of a rotary converter, however, is not such a simple matter as in motor-generator equipments, as variations of the field strength have little effect upon the direct-current pressure. It becomes necessary, therefore, to vary the alternating-current pressure by one of two means, the first being the use of regulating transformers, or induction regulators. The second method consists in compounding the rotaries, and inserting choking coils in the various leads, thus providing self-induction between the terminals of the transformer secondaries and the slip rings of the machine. This question, however, will be dealt with in Mr. Meyer's paper next January, and need not be further discussed now.

Having thus outlined the equipments, it becomes necessary to consider the working of the sub-stations, and the conditions governing the choice of the different types of machinery.

OPERATION OF SUB-STATIONS.

In considering the operation of converting sub-stations the following points may be noticed.

For small powers the simplicity and ease of running of an induction motor generator plant may justify its installation, as the attendance cost may be kept low in spite of the poor power factor. For large stations, however, this drawback would probably be insuperable. We are therefore left with the choice of synchronous motor-generators and rotary converters with transformers. Several factors govern the selection. In the first place a rotary converter equipment has distinctly the advantage in efficiency, and on this point the author would refer you to the figures below, which are a reproduction of those given in Mr. Field's valuable paper.

Extract from Mr. Michael B. Field's Paper on the "Relative advantages of Three-, Two-, and Single-Phase Systems for feeding low-tension networks," read before the Institution of Electrical Engineers.

Type of Equipment	†Synchronous Motor Generator	Synchronous Motor Generator	Rotary Converters and Step-down Transformers	Glasgow Rotary
Output of Sub-Station Converter	500 K.W.	500 K.W.	500 K.W.	500 K.W.
Speed of Converter ...	300 "	300 "	300 "	500 "
Number of Fieldpoles (Generator)	10 "	10 "	16 "	6 "
Peripheral Speed of Commutator	1880 "	1880 "	3100 "	3250 "
Number of Commutator Bars	270 "	270 "	560 "	324 "
Temperature rise, any part after 24 hours at full load	35° C.	35° C.	35° C.	30° C.* after 12 hours
Efficiency { Full load ...	86 per cent.	87 per cent.	92 per cent.	92·5
Efficiency { Half " ...	80 "	79 "	87·5 "	89·5*
Overload Capacity for one hour with fixed brushes	25 "	25 "	75 per cent.	50 p.c. * rise of T. = 60° C.
Power factor { Full load	91 "	100-96 " (Leading)	100-96 " (Leading)	—
Power factor { Half "				
Starting Current from A.C. side in terms of Full Load Current ...	50 " (Rotary Resistance)	100 per cent. (Starting Motor)	60 per cent. (Starting Motor)	—
Full Load drop of Speed	3 per cent.	None	None	None
Floor Space required per K.W. (square feet) ...	0·5	0·5	0·45	0·34

* Figures marked thus * are guaranteed by Contractors only.

† ERRATA.—For "Synchronous Motor Generator,"
Read "Induction Motor Generator."

As regards first cost there is little to choose. When, however, the question of periodicity comes to be considered, the weak feature of rotary converters appears. A rotary converter works admirably on 25 cycles, but as the periodicity rises its performance falls off, and above 40 cycles they cannot be regarded as perfectly reliable. A higher frequency requires either more crowded poles or a higher peripheral speed of the armature and the commutator of the converter. The former involves increased magnetic leakage and greater danger of flashing over from the brushes of one polarity to those of the other, owing to the short distance between them. A high peripheral speed is objectionable, as it increases the commutator friction and heating, and greatly increases the tendency of the brushes to spark and disentegrate. The E.M.F. common in tramway work, 500 volts, calls for a large number of armature slots and commutator segments per pole, and all of these must travel the full distance between the poles during each alternation, thus requiring with frequencies materially higher than 25 cycles per second, either very thin slots, teeth, and commutator segments, or a high peripheral speed and consequent centrifugal force cutting down seriously the factor of mechanical safety. With 50 cycles both disadvantages are unavoidable, the speed is excessive, and the slots, teeth and segments are crowded.

On the higher periodicities, moreover, rotary converters develop a tendency to get out of step, and are liable to large voltage fluctuations, which condition is known as "hunting." This phenomenon, which is well-known to all engineers who have had to run high periodicity converting sub-stations, occurs also with synchronous motor-generators, but not so frequently as with rotary converters. It is generally started by sudden fluctuations of the load and can often be stopped by adjustment of the field strength unless the case is very severe.

Frequently modern machines are fitted with "damping coils" or shields, which consist essentially of heavy flanges of copper attached to the edges of the poles, so that the alterations of armature reaction and of field are damped by heavy eddy currents whenever they arise.

We are, therefore, perforce compelled, for circuits where the periodicity is 50 cycles or upwards, to select synchronous motor generators for the main units of the sub-station plant. As before stated, an induction motor-generator set would, in a fair sized station, be provided to furnish direct current for starting up the synchronous sets in the event of the low tension network being dead.

The other parts of a polyphase equipment demanding consideration are the switchgear and the transmission line.

As regards the first, the high voltages used in alternating current work naturally demand special precautions in this part of the system. Very long air-break and oil-break switches are used, and whilst the former may give satisfactory results up to 5,000 and 6,000 volts, the best expert opinion is rapidly tending in favour of the latter, as in them the arc set up between the opening switch contacts is ruptured under oil at the instant of zero current, thus preventing a condition liable to set up large voltage fluctuations on the line with the consequent strain upon the insulation. For very large plants the main switchboard may be operated from a distance by a small control board governing small motors on each large oil-break switch.

The measuring instruments require, in most cases, that transformers be inserted into the main circuit so as to transform down either the voltage or the current. Further provisions have to be made in almost all alternating current stations for connecting the different parts of the plants in parallel. This requires either a lamp or a voltmeter for indicating the phase relation between the incoming machine and the bus-bars. When using a lamp for paralleling the connections should be made in such a manner that the machines are in phase when the lamp is bright, since a small difference in the phases can be easier detected with a bright lamp than with a dark one. In larger plants special synchronising devices may be used, which not only indicate the phase of the incoming machine, but also tell whether it runs too fast or too slow. Every precaution has to be taken to ensure safety for the switchboard attendants, and no bare high tension metal is allowed to be exposed on the front of the board.

With respect to the transmission mains the cheapest system is unquestionably that of bare overhead conductors carried on insulators and a pole-line as used abroad. There are, however, comparatively few instances in this country where this construction is permissible, and we have, therefore, to use the more expensive system of insulated mains laid in the ground. In order to reduce the self-induction loss, each cable should contain a complete circuit, *i.e.*, in a three-phase system a three-phase cable would be used. Owing to the great cost of insulation for extra-high tension underground cables it seems probable that higher voltages than 20,000 will be commercially impossible in Great Britain. In bare overhead lines it is practically possible to raise the voltage limit to the point at which the cost of insulating devices equals the reduction in cost of conductor due to higher voltage. This limit is variable, depending largely upon climatic conditions, but in America 35,000 or 40,000 volts are regarded as quite

practicable with ordinary precautions, and at least one station of 4,000 K.W. capacity (the Standard Electric Company of California) is working at 60,000 volts.

The loss of energy from leakage under these conditions is generally about 3 per cent., but owing to the fact that the dielectric strength of the air is a varying quantity it is not probable that many attempts will be made to work at much above 50,000 volts.

As regards the limits of distance of transmission, the longest line the author is aware of is that between Colgate and Stockton, U.S.A., a distance of 216 miles, operated by the Bay Counties Power Co., and during August, 1902, power was transmitted by this Company to Sacremento, a distance of 270 miles, with entire success.

The latest results attained in America enable the following average percentages of efficiency and loss to be ascertained, assuming a power of 10,000 K.W., or 13,400 H.P., delivered at a point 300 miles distant:—

	K.W.
Power delivered	10,000
Up to Step-down Transformers, 98 per cent. efficiency	10,200
Up to Transmission line, 70 per cent. efficiency ...	14,600
Up to Step-up Transformers, 98 per cent. efficiency ...	14,900
Up to Generators, 96 per cent. efficiency	15,500
Up to Water Turbines, 80 per cent. efficiency ...	19,400
From Water Mains from falls, 90 per cent. efficiency...	21,600

This represents a delivery to the consumer of 46 per cent of the actual power of the water at falls. It will be observed that the efficiency of the electrical portion of this plant would be practically 64 per cent.

Having thus dealt with long distance transmission plants mainly with conversion to direct current, the author would refer again for a moment to the second main class previously mentioned, which are purely alternating current. Alternating current transformer sub-stations taking power from high tension lines for local distribution do not need comment, but the numerous low voltage polyphase factory and mining plants are worthy of notice. They are generally combined power and lighting installations working at from 220 to 550 volts and 50 cycles, and almost invariably use induction motors exclusively, the lighting being sometimes balanced across all the phases and sometimes specially arranged for on one phase only.

In cases where absolutely constant speed is of value a motor equipment of this type is superior to a direct current one, as under

constant load the speed of the motors is the same all day, given a constant prime mover speed, whereas with the best direct current plant a rise of speed with the heating of the fields of the motors cannot be prevented. There are instances where this consideration is of very great value.

In passing it might be interesting to mention that upwards of 75,000 H.P. of polyphase motors are either running or being installed in cotton mills in the States, and probably as large a capacity is in use for mining work. In this country the number of industrial polyphase plants is rapidly increasing.

In considering the other purely alternating current installations mentioned under the second class, viz., the power stations supplying without any conversion to direct current, these would usually be worked at not less than 50 cycles. The choice of two-phase or three-phase for such plants is a matter demanding consideration, and in comparing the two systems one finds advantages on both sides. With regard to the copper investment, the following table shows a decided advantage on the side of the three-phase system:—

Copper required for transmitting a certain energy at a given loss for equal voltages at the receiving points :—

Two-phase, four wire	100 per cent.
Two-phase, three wire	73 "
Three-phase, three wire	75 "
Three-phase, four wire	30 "

On the other hand, a two-phase system may be superior for lighting installations, where the two phases can be worked independently, since in that case a simpler distribution net work will result. A number of other points may be brought forward in favour of the one or the other, the author thinks he does justice to both if he expresses himself as follows. From the point of view of the supply station engineer, the two-phase system is often to be preferred, since it gives less work in balancing the voltages at the lamps, and also shows somewhat greater reliability when keeping the two phases separately. From the financial point of view, the three-phase system using a fourth wire as neutral is the best, since here a considerable saving in capital investment can be effected. Both systems are extensively used, and have given entire satisfaction. Therefore it should be left to the individual cases to decide which system to choose.

In designing a polyphase installation it is necessary to have some

idea as to the probable power factor of the system, and the following table gives a general idea of what may be anticipated under normal conditions :—

PROBABLE POWER FACTORS.

Incandescent Lighting	95 per cent.
Mixed Lighting	85 "
Synchronous Machinery	95 "
Well loaded Induction Motors	80 "
Average " " ...	50 to 60 "
Average loaded Induction Motors and equal amount of Incandescent Lighting	70 "

Before concluding with a few particulars of some installations of general and local interest, the author would make one or two remarks concerning the probable developments of alternating current working in the near future.

Nothing has been said to-night concerning polyphase traction, which is in itself a large and interesting question and which, for railway work proper, offers immense possibilities.

The author would refer you, however, to the work done by Messrs. Ganz of Buda-Pesth, with their concatenated system of control of polyphase motors, on various small continental railways, particularly in Northern Italy, and also to the high speed Berlin-Zossen line of Messrs. Siemens & Halske, and the Allgemeine Electrical Co. in Germany, where a speed of 130 miles an hour has been attained. Many leading experts, however, consider that the future will be to a single phase system of long distance railway traction, having regard to the great success of a series of experiments in this direction carried out by the Union Elektricitäts Gesellschaft of Berlin. The simplicity of a single phase installation of course offers great advantages in this connection, if the questions of speed control and starting torque have been solved. This matter, however, hardly comes into the scope of the present paper.

With respect to the driving of alternators, it is probable that the day of the reciprocating steam engine for alternator driving is drawing to a close, and that the coming prime mover will be (at all events for large units) the steam turbine, or the gas engine working with producer gas. A steam turbine set can be made for satisfactory running, having a quarter the weight, and taking up one-tenth of the floor space of a similar slow-speed reciprocating steam engine set. Speaking

within certain limits, the higher the speed of an alternator the better is its performance. A further advantage of the steam turbine is its absolutely even turning moment, doing away with the cyclical irregularity of speed of rotation, which is a drawback of the reciprocating engine.

With modern alternators the maximum phase displacement should not exceed 6 degrees, equivalent to a synchronising current of 10 per cent. of short-circuit current, degrees of phase displacement being degrees of angular displacement multiplied by the number of pairs of poles on the field magnet system. For 25 cycle generators the cyclical irregularity of turning moment should not exceed 1-200th, and for similar 50 cycle generators having laminated pole shoes, the cyclical irregularity should not exceed 1-300th. For 50 cycle machines, moreover, damping coils either through or round the pole shoes can be employed with advantage. For parallel running it is therefore obvious that low periodicity generators will be simpler to operate than generators of high periodicity.

The gas engine working with producer or blast furnace gas whilst not in itself so satisfactory a prime-mover for an alternating-current generator as a steam turbine, is exceedingly economical, and therefore presents great possibilities, particularly where the advantages of an ammonia recovery plant can be utilised in conjunction with the producer plant.

With reference to particular instances of polyphase plants: the author would mention that the first three-phase installation put down in this country was installed in Liverpool some 8 or 9 years ago at the North Dock Silos of the Liverpool Grain Storage and Transit Co. This plant, which consists of a three-phase generator with revolving armature about 100 kilowatts capacity, driving two or three induction motors for marine elevator legs for handling grain, has given every satisfaction since it was first installed, and is running perfectly at the present time. The plant was made by the Oerlikon Company, Switzerland, and although the machines differ in a number of constructional details from those now manufactured, their external appearance is very similar.

As regards more modern plants: A very interesting three-phase installation, consisting of a main plant with sub-stations, has been put down by the British Thomson-Houston Co. for the Liverpool Corporation Electricity Department. This plant consists of three 800 kilowatt three-phase 50 cycle 6,600 volt generators, the sets being driven by Willans engines, and six induction motor-generator sub-stations at Lodge Lane, Lark Lane, Fairclough Lane, Smithdown

Road, Laverock Bank, and Cobbs Quarry. The most notable thing about this installation is, that all the smaller induction motor-generators, including some of 150 kilowatt capacity, have transformers to reduce the voltage on the motors to about 220, which is not quite in accordance with usual practice. The high tension switch gear is of the oil break type, with each switch contained in a separate brick cell, and operated from a distant switchboard by means of a system of rods and lever gear. The cables used are three core, armoured. It is proposed to greatly enlarge the three-phase plant at Lister Drive, and to contain the main generating machinery a new station is being built; in all probability some steam turbines will be used in this station, and the units will be about 3,000 H.P. each.

The largest and most important three-phase plant in Lancashire at present is that belonging to the Manchester Corporation Electricity Department, which consists of six 1,800 kilowatt sets now installed and running at Stuart Street Station, and two 3,800 kilowatt sets which are about to be erected. The smaller sets have vertical marine type engines manufactured by Yates & Thom, running at 93 revolutions per minute, and the two large sets will have Wallsend Slipway engines. The plant is generating three-phase current at 50 cycles, 6,500 volts, and the energy is being transmitted to 23 sub-stations. The generators are rather interesting in that they have the fixed armature, held, not in a heavy casting as usual, but between two cast iron cheeks held together by a system of tie-rods arranged bicycle frame fashion. This design, which is stated to reduce the weight of the machine 20 per cent., and its cost 10 per cent., was introduced by the Allgemeine Company, but although electrically the machines are fairly satisfactory from a mechanical standpoint, they might easily be improved, as it was found in running that there was a considerable lack of lateral stiffness, and in consequence cross tie-rods had to be fixed. With respect to the sub-stations: the converting units consist almost entirely of synchronous motors wound for the full line voltage, direct coupled to generators, some of which are wound 500-550 volts for traction purposes, and some of which have a double-wound armature giving 2×200 volts for lighting. These latter generators are interesting, as the armature windings are tapped off on to slip rings, the slip rings connected up through a choking resistance and the middle point of this resistance connected to the neutral of the three-wire distributing net work. Any out of balance current is taken care of by this arrangement. The sub-station units are principally of about 250 kilowatts capacity. The sets are started up from the direct

current side, and synchronised on to the high tension board, and an induction motor balancer set is provided in each of the large sub-stations to provide direct current in case the low tension net work should not be charged.

All the high tension mains are laid in duplicate.

The switch gear in both main station and sub-stations consists of large air-break switches operated by levers, the handles of which only project from the front of the switchboard, and there is an insulating panel between each phase of the triple pole switches. The fuses are contained in large glass tubes almost filled with plaster of Paris, and the fuses themselves are mounted on small carriages or trucks which can be drawn out and so disconnected in the event of the fuses having to be replaced. The whole switchboard is typical of German design and practice, and compares very unfavourably as regards size or simplicity with the oil-break switchboard at Liverpool.

Great care is taken at Manchester in charging the cables up slowly, so as to avoid surging effects.

On the Continent, one of the finest installations is that of Berlin, at Oberspree, which contains about six 2,000 kilowatt sets driven by slow speed Sulzer horizontal engines, the generators being built by the Allgemeine Company, but not having the form of armature construction used for Manchester. These sets also ran distinctly better than those at Manchester have done up to the present.

A notable installation in this country is that of the Walker & Wallsend and the Newcastle-upon-Tyne Electric Supply Company, who put up what was the first station in this country for the supply of electricity in bulk. The present power station is at Neptune Bank, Tyneside, but another large station of turbo-generators is being completed by the Company at Carville. The station supplies electricity in bulk to the Walker & Wallsend Gas Company for sale to the shipbuilding yards, works, &c., at Wallsend, Willington and Willington Quay; supplies the sub-station of the Newcastle-upon-Tyne Electric Supply Company for general purposes; the Tyneside Tramways Company; the County of Durham Electrical Power Distribution Company, and also the North Eastern Railway Company, with a supply of current for the electrical working of certain portion of their line in the Tyneside district. It will, therefore, be apparent that this Power Company has a singularly good and varied load, having probably the best district of its size in the country.

This power station was designed by the Gas Company for supplying

three-phase current at 5,500 volts with a periodicity of 40 cycles. The sub-stations are supplied at this pressure, and are provided with static transformers and synchronous motor-generators, both supplied at the full voltage, whereby current may be obtained either at 440 volts three-phase for motive power, or at 480 volts continuous-current on the three-wire system for both lighting and power. When the power station was taken over by the Supply Company, the increase in the area of distribution suggested the desirability of increasing the primary voltage; this was, however, abandoned, as the saving in copper was almost counterbalanced by the increased cost of insulation required by the Board of Trade.

The equipment of plant in this power-station is as follows:—

Eight Babcock & Wilcox boilers;

Two 300 B.H.P. Belliss engines, each driving two 100 kilowatt 240 volts continuous-current generator;

One 75 B.H.P. Belliss engine, driving 50 kilowatt 240 volts continuous-current generator;

Four 1,000 I.H.P. triple expansion engines, each driving a 700 kilowatt 5,500 volts three-phase alternator;

One 1,500 kilowatt Parsons turbo-alternator, 5,500 volts three-phase; and

One 150 kilowatt 5,500 to 240 volts three-phase continuous-current synchronous motor-generator.

The engines driving the 700 kilowatt sets are all of Tyneside manufacture—of the triple-expansion vertical inverted type, *i.e.*, practically marine engines fitted with suitable governors and valve gear. The first of these was constructed by the Wallsend Slipway and Engineering Company, and the others by Messrs. Wigham, Richardson & Co.

The main generators are the revolving-field type, and give an output of 700 kilowatts at 5,500 volts, the speed being 100 revolutions per minute, and the commercial efficiency of the generators is not less than 95 per cent.

A cellular type Ferranti switchboard was originally installed for the high tension circuits, but is now being changed for an oil-break switchboard. The Company has 130 miles of mains laid, and their works cost for power at the switchboard is ·324 pence per unit.

A number of Power Companies similar to this are either being projected or being constructed in this country, and there is no question that many of them should have a wide field of usefulness and be commercially successful. It is, however, absolutely essential for

such concerns that the load factor which they are likely to obtain should be satisfactory.

With these remarks concerning power supply companies in general, the author will conclude a paper which, he fears, must have been rather too long for the patience of some, but as stated in opening, it is exceedingly difficult to keep any remarks on a subject so large down to a reasonable length. He does not pretend that the information given contains anything at all novel or striking, as his remarks have only been intended to give some outline of recent practice in alternating current working, and to a certain extent at all events to prepare the way for the gentlemen who are reading papers which will deal with particular aspects of the subject more in detail.

DISCUSSION.

Mr. A. H. Robinson said—On page 78 of the paper, the author says—"The cost of distributing circuits for direct current is, therefore, "very much greater than for the low tension alternating-current "circuits, to which current is supplied from a large number of "transforming points." Mr. Robinson

Now I cannot see quite why this difference should be so great. On the one hand, you have a small number of comparatively expensive sub-stations, and on the other hand, a large number (to quote the author's words) of transforming points, each requiring a chamber transformer, or transformers and switch-gear, and which though individually costing a comparatively small amount (as compared with the sub-stations), in the aggregate amount to a quite respectable sum. I think that a comparative table of costs would be of considerable interest.

On pages 80 and 81, the author speaks a good deal about power factors. Now, quoting a very high authority on polyphase working, Mr. Esson, he says, with special reference to synchronous motors:—"Now, it is a mistake to suppose that for a synchronous motor the "power factor is always, perhaps I should say, is ever unity. It "depends upon the field excitement, and upon the adjustment of the "E.M.F. curve of the motors to that of the generators. I have "found great difference in the power factor of a motor accordingly "as it is put on the Blackheath Supply Company's, or on our "own mains at Chorlton, and in the synchronous motor of a motor "generator it may easily be below ·95."

Again, with reference to non-synchronous motors, Mr. Esson says:—"In the first place, it must be remembered that motors running in a "sub-station have a high power factor as compared with motors of "mixed sizes, some full, and some partially loaded, running on a "general polyphase system of supply. In the latter case, the power "factor will be from ·6 to ·7, while in the former, owing to gradually "improved design, it may be over ·9. In an article in the 'Electrical "World,' of New York, Mr. Mershon asserts that recent require-"ments of a full load power factor of ·92 have been met, while "a power factor as high as ·6 has been realised."

Mr. Robinson I think, then, that this presents a very strong case for the non-synchronous motor, and taking into account the greater reliability and simplicity, I think they are undoubtedly the best in most cases.

The author states that for large sub-stations, owing to this power factor bogey, non-synchronous motors are impossible. Now, if I have succeeded in laying this bogey, there is only the question of size. Well, 1,000 H.P. non-synchronous motors have been built, and still larger could be if wanted.

As regards rotors, it is true that they are slightly more efficient than synchronous or non-synchronous motors. With anything over 50 cycles, they are the cause of a tremendous amount of bad language. Steinmetz, in dealing with this subject, says :—"When properly handled and taken care of, under reasonably "fair conditions, the rotary at such a frequency (*i.e.*, 50) will do its "work well, but the more you become familiar with it the less you "are confident that you can rely upon it in an emergency, and that "it will not go back on you when you need it most."

I have only one more point to mention, and that is with reference to the remarks on page 92, as to gas engines. The author prophesies great developments for the gas engine. As regards space occupied and even turning moment, the steam engine is undoubtedly better than the gas engine at present, while as regards efficiency, I was looking at "Lightnings" tables this afternoon, and noted only three gas engine stations, and they did not compare favourably with steam driven stations of similar capacity, and low tension non-condensing stations at that. There is, I think, plenty of room for improvement in the gas engine.

Mr. Worrall Mr. G. W. Worrall said—I do not know whether visitors are permitted to join in the discussion, but if so, I should like to make a few remarks.

On page 88, the author says :—"Very long air-break and oil-"break switches are used, and whilst the former may give satisfactory "results up to 5,000 and 6,000 volts, the best expert opinion is "rapidly tending in favour of the latter, as in them the arc set up "between the opening switch contacts is ruptured under oil at the "instant of zero current, thus preventing a condition liable to set up "large voltage fluctuations on the line with the consequent strain "upon the insulation."

At the British Association meeting last September, Mr. Woodhouse read a paper on "Protective Devices for High Tension Systems." In the course of his remarks on oil-break switches, he stated that the

circuit was broken at the instant of zero current. In the discussion this was disputed, some engineers maintaining that the oil caused the circuit to be broken slowly, others quickly. Mr. Worrall

Prof. Marchant and myself are carrying out some experiments in this connection. We have connected a Duddell Oscillograph up to the circuit, so that we can record the normal current wave, and also the P.D. wave across the switch contacts on switching off. With a capacity load, such as unloaded cables, the current is nearly 90° out of phase with the P.D. Hence, if the circuit be broken at the instant of zero current the P.D. is at its maximum value. So far we have only tried air-breaks with such a load, but we find that by switching off at zero current, the P.D. having its maximum value, the entire wave is displaced by an amount equal to its maximum amplitude. Thus the P.D. across the switch contacts is double its maximum instantaneous value.

On the same page the author says :—"The measuring instruments "require, in most cases, that transporters be inserted into the main "circuit so as to transform down either the voltage or the current." With regard to the voltage, I may say that Prof. Marchant and myself have devised a capacity multiplier for use on high tension circuits, in combination with an electrostatic voltmeter. The multiplier absorbs no energy, is simple in construction and cheap. We expect to have it on the market shortly.

Mr. P. B. Coulston said—There are several points in connection with the paper upon which I should be glad of further information. Mr. Coulston

Firstly, as regards the starting up of synchronous motor generators, is it not possible to start up on low periodicity circuits, from the alternating current side with the field open in a similar manner to that described for rotaries. It might, of course, be difficult in the case of extra high tension plant, but I should like to know if it is ever done.

As regards rotaries, the author says:—"A rotary converter is, "speaking generally, a continuous current generator with symmetrical "points on the armature winding tapped off to slip rings," and in this connection I remember hearing that when the General Electric Company, of America, first commenced to make rotaries, they used their standard direct current frames and armatures, but afterwards found it advantageous to reduce the cross section of the yoke, and to increase the number of poles, using standard armatures.

With respect to the use of transformers with the induction motor generators in Liverpool, I would suggest that as this is American

Mr. Coulston machinery, and the General Electric Company's practice has always been to use rotary converter sub-stations with transformers, the habit of using transformers was too strong for them in this instance, although they were induction motor sub-stations.

In speaking of the Manchester sub-station, the author says that great care is taken in charging up the cables slowly to avoid surging effects. I should be interested to hear how this is arranged for.

A point which I anticipated from the first portion of the paper that the author would emphasize more than he did, is the advisability of, so far as possible, doing away with conversion to direct current, where the transmission conditions and local circumstances make the use of an alternating current main-station imperative.

To consider the case of Manchester, if it had been possible to avoid the use of the converting sub-stations, the cost of the equipment would have been immensely reduced. Efforts ought to be made by special inducements, as regards price, to persuade consumers to take alternating current through step-down transformers from the high tension mains. This should apply particularly to the outskirts of the area supplied.

Mr. Kemp Mr. J. P. Kemp said—The last speaker asked if it were not possible to start up synchronous motor generators on low periodicity circuits from the alternating current side. I may say it is "possible," but, at the same time, there is the difficulty with the field of which he spoke; such synchronous motors when fitted with amortisseur coils have been run practically as induction motors. They have had the field open, and the motor has run without any difficulty, but with a low power factor and a very great increase in the current.

There are several points in the paper which particularly interest me. One is, the power factor of synchronous motors. I must say I cannot understand how you can get a power factor that is greater than unity. If you get past unity you get below again, and, of course, as the author says, this effect is generally the result where there are synchronous and induction motors on the one circuit; the induction motors cause a lagging current, and the synchronous motors if over excited act as rotary condensers and cause a leading current, the resultant power factor being almost unity.

I may mention that at Stuart Street Station we always contrived to run with a power factor of unity, this was effected by regulating the fields on the main generators and the synchronous motors.

The last speaker also referred to the charging up of the cables.

This was effected in various ways, but was usually done by means of a small motor, driven by a three-phase generator, connected to a three-phase transformer, which stepped up to 6,500 volts, and, if necessary, up to 10,000 volts. Mr. Kemp

This method has many advantages, and the apparatus could be used for carrying out Board of Trade pressure tests on the H.T. plant and switchgear.

About seven or eight months ago, Mr. Cowan read a paper before the Manchester Section of the Institute of Electrical Engineers, in which this and a few other methods of charging cables were described.

It was suggested at the time that the apparatus mentioned could not charge the cables quickly enough, but from personal observation I found that the engineers have been able to charge them up in from 40 to 60 seconds, which is quite quick enough for ordinary practice.

The method of balancing designed by Mr. Dobrowolsky is found to be most satisfactory, the continuous current end of some motor generators is arranged with slip rings, and is, in many ways, similar to a single-phase converter. A choking coil is connected across the A.C. brushes, and the middle wire of three-wire system is connected to the centre of winding on choking coil.

I may say that this is the principal method of balancing adopted in Manchester at the present time. Another system which they had there at one time, was used in connection with three-phase rotary converters; in this case the converters supplied the outers of a three-wire system, the middle wire of which was connected to the neutral point on the L.T. side of three-phase step-down transformers; this effected a satisfactory balance.

The cyclical variation of generators is another point touched upon in the paper.

This is of great importance with alternators, but it does not matter how careful the manufacturers of engines may be, a good deal of variation may occur later, owing to indifferent valve setting. This has a marked effect on the turning moment, and in such cases when the alternator is switched in parallel with another, it is easily possible to have wattless cross-currents between the machines, almost equal to the full load current.

At one time I had some difficulties with this matter, but they were overcome by running the engine cranks in step before synchronizing. This was effected by a simple telephonic device, which was connected

Mr. Kemp to the valve gear of engines, and by listening to the telephonic receiver (on switchboard) you could tell by the click of instrument if the cranks of incoming engine were in step with the one on load.

The losses in sub-stations is a very important matter indeed, and amount to a considerable percentage of the energy generated.

There is one point I might mention, and that is in connection with the machines in Stuart Street Station—of which the author says, on page 93, "although fairly satisfactory electrically, they "might be improved"—the tie rods are arranged to stiffen the armature, and allow for a certain amount of adjustment, and, I must give credit to the makers that—with the exception of the small amount of vibration which was visible—the machines ran exceedingly well.

Mr. Miller The President, Mr. THOMAS L. MILLER, said—Before calling upon the author to reply, I should like to make one or two remarks on the paper, and also on points that have been raised in the discussion.

In reading his paper the author referred to the Board of Trade Regulations regarding extra high tension cables. I do not know whether he had in mind the Board of Trade Rules, as printed, with regard to the insulation of high tension cables, but I think Mr. Trotter has recently pointed out that these rules were not intended for the extra high tension cables which will be used in the high power schemes, and that he was quite prepared to receive suggestions from cable manufacturers and others with regard to the thickness of insulation for such extra high tension cables; and that he has further stated that he will be prepared to consider the use of overhead conductors under certain circumstances, provided precautions are taken to safe-guard the public.

With regard to Mr. Kemp's remarks, as to the running of the cranks in step when alternators are parallel, I believe this system is adopted in certain stations on the Continent, and that it gives very good results.

The only point I should like to refer to, is Mr. Robinson's remark with regard to the results obtained from steam driven and gas driven stations. In making his comparisons, Mr. Robinson has taken the records from some of the out-of-date gas driven stations, and has compared them with the up-to-date steam driven stations.

I think, however, there is only one gas driven station that we may term modern, and that is the one recently put down at Walthamstow, the results from which compare very favourably with the cost of any

of the London stations; and in making comparisons it would, I think, be fairer to compare the Walthamstow costs with the steam driven stations in that district, than to take the cost of the out-of-date gas driven stations I have referred to, and compare them with the up-to-date steam driven stations. Mr. Miller

I may say I referred to this point in my address, and gave comparative figures which may be of interest.

Mr. H. W. Wilson, in reply, said—I must thank you for the patient hearing which you have given to a paper which, I fear, must have been somewhat uninteresting to a good many present, and I must also thank the gentlemen who have taken part in the discussion for the remarks they have made. I am aware that I have made several statements to which objection might be raised, and I will endeavour to answer as far as possible these various points. Fortunately, however, some of the gentlemen who have spoken have already answered some of the questions raised by those who had previously spoken, and this, I am glad to say, will shorten my reply. Mr. Wilson

Mr. Robinson takes exception to the statement on page 78 concerning my comparison between the costs of cables for alternating current stations with transformers, and alternating current stations with direct current sub-stations and distributing circuits. I think, however, that if Mr. Robinson knew of the high authorities upon which these statements were made, he would treat the remarks with greater respect. If Mr. Robinson considers the matter again I am sure that he will admit that the capital cost of a system with direct current conversion must inevitably be much greater than that of a purely alternating-current plant. He must also allow for the much higher costs of running on account of the amount of skilled attention required in the converting sub-stations. To give accurate figures showing the comparison between the two systems for any given area would involve a large amount of work, but I have gone into the matter at times and there is absolutely no doubt as to which is cheaper in first cost.

Mr. Robinson also disapproves of the statement: that for a converter sub-station synchronous motor generators are to be preferred to induction motor generators on account of the lower power factor of these latter machines. In this connection Mr. Robinson quotes some figures of Mr. Esson, which are, of course, extremely good, but personally I am afraid they are too good to be true, and there is no doubt that the general results obtained with induction motor sets would not allow of the fixing of the value of the power factor in anything like as high as Mr. Robinson states. While I admit, of course,

Mr. Wilson that the running of an induction motor set is simpler than that of a synchronous motor set, and distinctly state so on page 86, I do not think that for a large sub-station there is much question as to the superior advantages of synchronous motor sets.

Mr. Robinson again disapproves of my assumption that the gas engine will come into extensive use for power stations on account of its high economy, and quotes figures to show that the only gas engine stations in this country are working at a higher fuel cost than steam engine stations. As, however, the President points out, these are old stations working under bad conditions and cannot be held to justify a fair comparison. Mr. Robinson will, I know, admit, that the possible thermal efficiency of a gas engine is probably double that of a steam engine, and there is no question that the fuel costs can be greatly reduced by the use of these prime movers. I am sure, therefore, having regard to the probable improvements in gas engine construction during the next ten years, many stations will be driven by gas engines using producer plants with ammonia recovery plants.

Mr. Worrall raises the question as to whether my statement: that the circuit is broken by an oil break switch at the instant of zero current is correct, and quotes results obtained at the University which tend to prove that this is not so. Upon this point Mr. Worrall can speak with more authority than I can, and I am merely assuming that the statements made by the General Electric Company of America and other manufacturers of oil break switches are correct, but I should not be surprised to find that they are under some misapprehension on this point, and I think that the experiments which Mr. Worrall is making will tend to throw some light on the subject. Several well-known authorities have assumed that the circuit is ruptured at the instant of zero current, and until it can be satisfactorily shown that this does not occur it is a convenient assumption, and there is no doubt whatever that for extra high tension work oil break switches are unquestionably superior to any other type now in use.

I was very much interested in Mr. Worrall's remarks concerning the double condenser apparatus that he has been using, and think that his remarks about rotors are quite correct.

With regard to Mr. Coulston's suggestion on the advisability of getting people to use alternating current on the outskirts of large towns, I think that this point might have more attention given to it by station engineers than there has been up to the present. My experience is that direct current is fashionable in this country, but if you can once get a man to take alternating current he is generally

very well satisfied with it and you can get others to follow. If we could do away with some of the direct current conversion plant it would be possible to supply power in outlying districts of the large cities much more cheaply, which is a very important point. Of course I am aware of the fact that the question of speed variation is of vital importance to some manufacturers, but I think we are apt to somewhat exaggerate the number and importance of such cases. Mr. Wilson

I do not think that Mr. Kemp's remarks call for much reply, and I am much indebted to him for practically answering several of the points which have been raised and so obviating the necessity of my replying to them. I was not quite clear before he spoke as to the exact method of charging up the cables at Manchester, whether they first brought the speed of the charging set up to normal and then strengthening the generator or field, or whether the field was constant and the speed varied, though this did not appear to be a reasonable assumption of the surging effects that might be set up by the periodicity variations. I am glad to have this matter cleared up.

As regards the battle of the systems: It was assumed a few years ago in this country, at all events, that the battle was completely over, and that single-phase alternating currents might be regarded as practically dead. Latterly, however, the improvements which have been made in single-phase motors have been so important that it looks possible that eventually single-phase working may replace a good many of the systems which we now have.

Mr. Miller commented upon Mr. Kemp's remarks as to the parallel running of the cranks on the Yates and Thom's engines at Stuart Street, and that he thought this practice was also adopted abroad. It is now used, I believe, in several places, but the first instance that I am aware of was that of the large single-phase plant at Frankfort, where the cranks of all the engines are synchronised.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

FIFTH MEETING—13TH JANUARY, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E., PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz.:—Mr. E. M. HOLLINGSWORTH and Mr. GEORGE E. SNOXELL, as *Members*; Mr. J. B. C. KERSHAW was transferred from the class of *Associate* to *Membership*.

MOTOR VEHICLES.

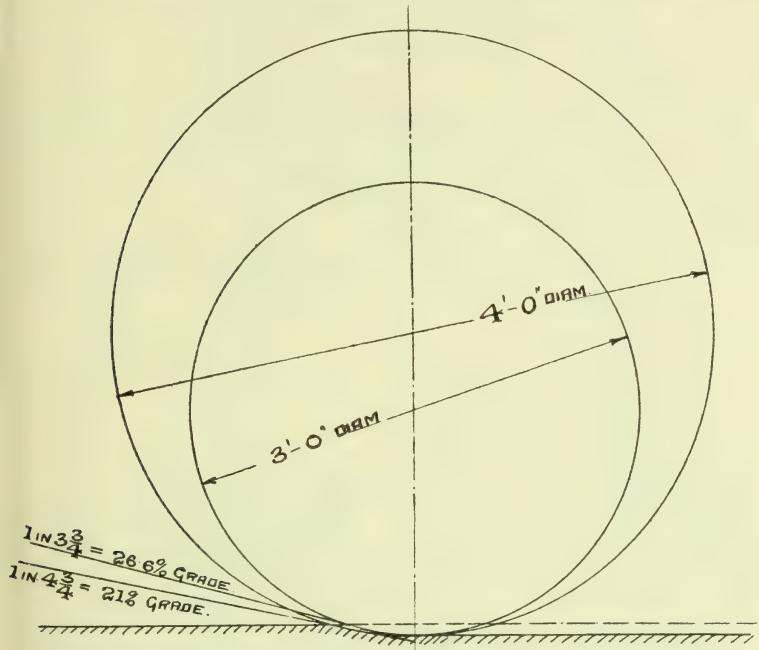
BY W. NORRIS, Assoc. M. Inst. C.E., M.I. Mech. E.

MOTOR traction within the last few years has made such rapid progress that the author does not feel he need apologise in selecting the subject. Various systems have been tried, but the one system which has proved itself more reliable than any other is steam.

Before dealing with the practical difficulties encountered in producing a reliable and efficient vehicle, it may not be out of place to say that steam road wagons may be classed in three types: (*a*) Boiler in front, engine underneath frame, gear transmission and "live" axle. (*b*) Boiler in front, engine underneath, double chain transmission and fixed axle. (*c*) Boiler in front, engine underneath, single chain transmission and "live" axle. I will, therefore, endeavour to confine my remarks to these types.

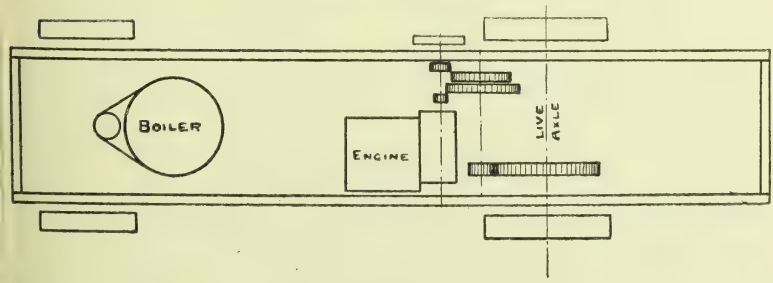
The Light Locomotives Act of 1896 fixes the tare at three tons, with no restriction as to the load carried, and although it has not

been possible to build a steam road wagon capable of carrying a load of four tons, leaving a tare of three tons, with the necessary factor of safety to ensure permanent working, yet I venture to say that the heavy motor industry would not have made such rapid progress had builders been allowed to design the wagons without any such restriction of weight. There is very little doubt but that the industry



RUT DIAGRAM.

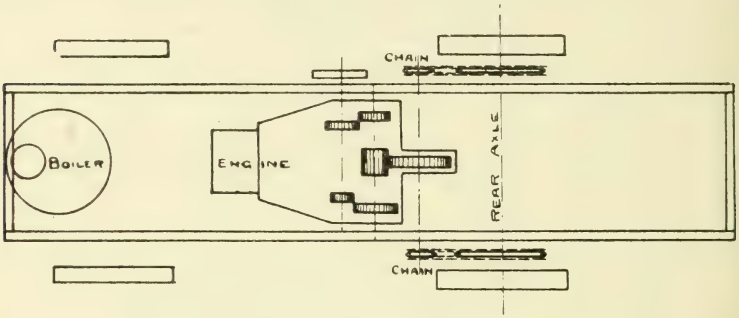
FIG. 1



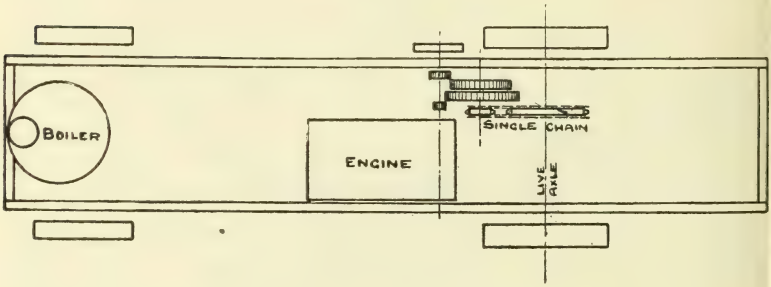
THORNYCROFT SYSTEM

FIG. 2

would have been held back to a large extent if we had an unlimited tare. The various formulæ used in ordinary engineering practice have been of little service to the self-contained motor wagon builder. Locomotives using a permanent track do not come under the same category as steam road wagons, because locomotives depending on adhesion do not, as a rule, climb worse gradients than 1 in 50, which is scarcely comparable with the gradients asked of the motor



LEYLAND SYSTEM
Fig. 3



STRAKER SYSTEM
Fig. 4.

wagon. Everton Brow, for instance, with its 1 in $9\frac{1}{2}$ gradient, was negotiated with ease, in the 1901 trials, with wagons having a load of five tons, and driving wheels with a smooth surface. In short, the track for locomotives is levelled to suit the best running conditions, whilst the motor wagon must be designed to take the roads as they exist. Although it is absolutely necessary to keep the pressure per square inch of road contact as low as possible, in order to reduce injury thereto to a minimum, it is obvious that a wide tyre on the

majority of roads would not be in contact for more than one-half its width, owing to the camber of the road, and even where roads are fairly flat, and if paved with "petrified kidneys," as is the case in some Lancashire towns, then the tyre contact resolves itself into a

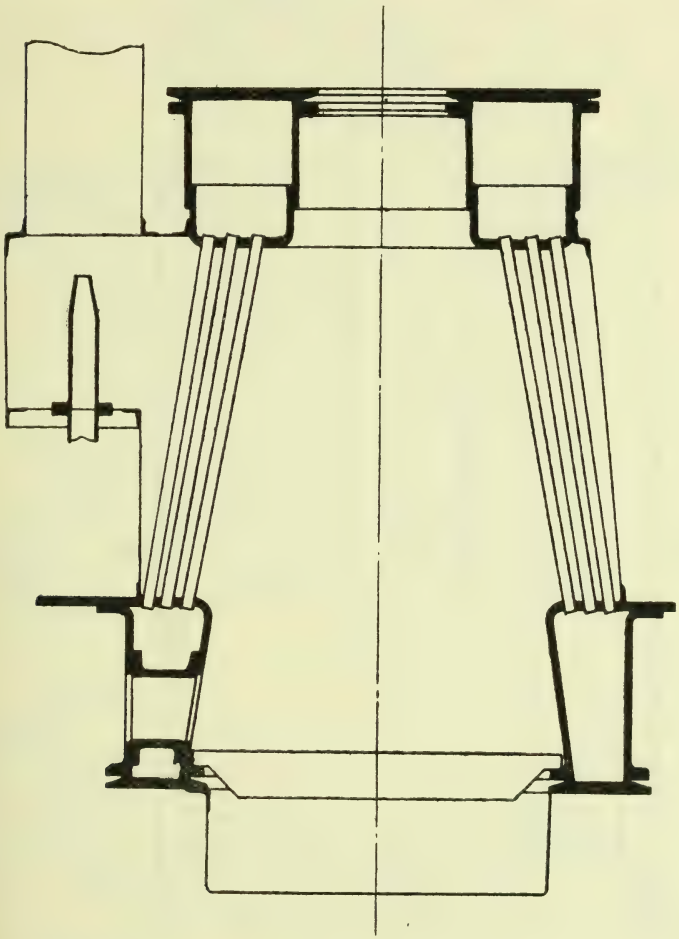


FIG. 5.

series of point contacts. For ease of running there can be no question as to the advantage of a large wheel over that of a small one, but the difficulty we are met with is the height of the existing loading platforms, and since we are hampered with a 6 feet 6 inch

width of platform, as against a 7 feet 6 inch in the case of horse lorries, it is not possible to have the wheels higher than the platform without

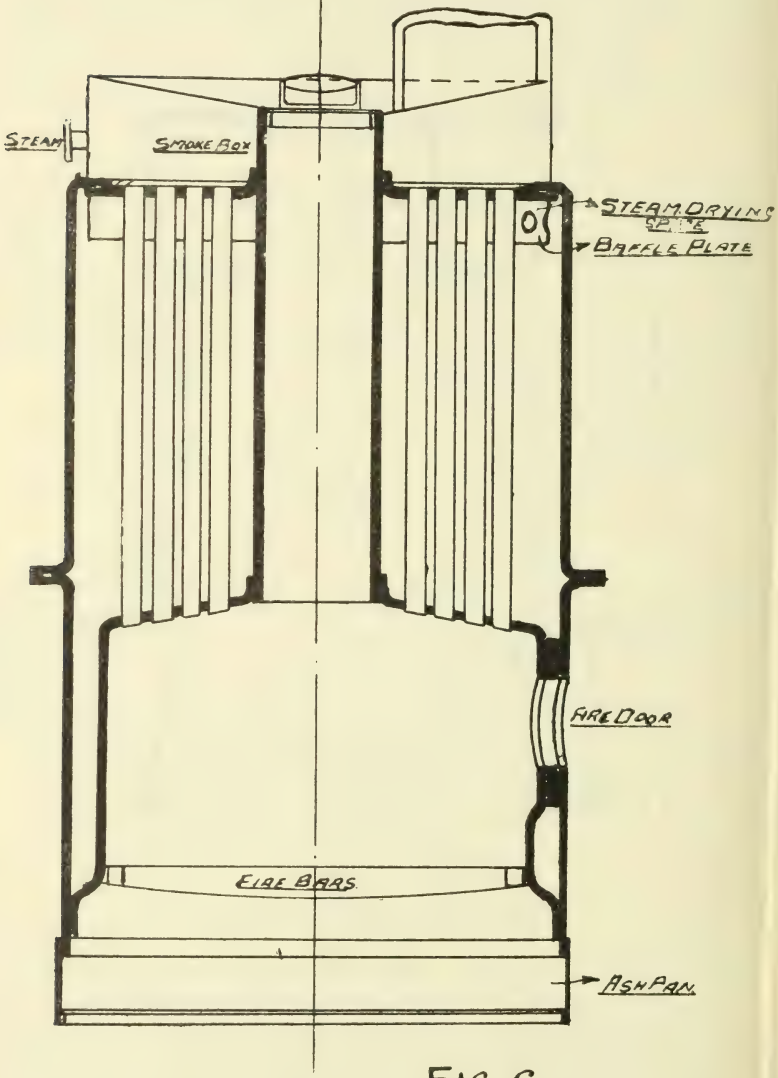


FIG. 6.

reducing the width to such an extent as to place the motor wagon out of competition with the horse drawn vehicles. One of the

initial difficulties was the three ton tare, which, as already mentioned, does not admit of conveying a load of four tons on its own platform.

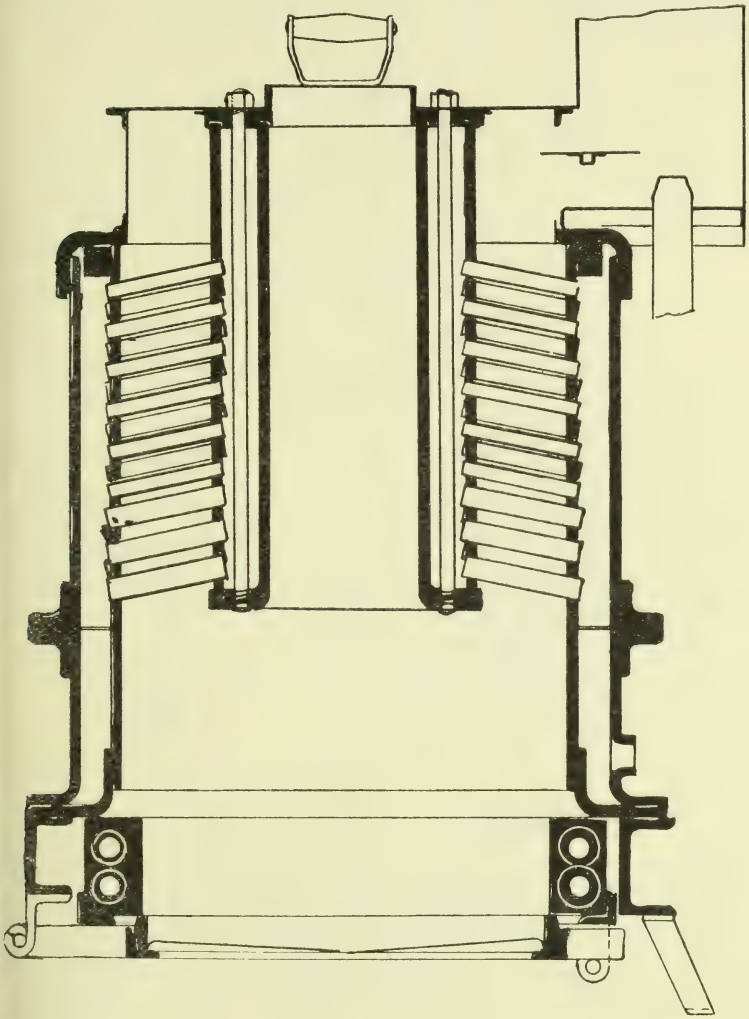


FIG 7.

In the 1901 Liverpool trials, one steam wagon carried an average load of 4·8 tons, and came within the three ton limit. This machine ran remarkably well, proving itself to be the most economical in fuel

and water. The consumption of common coke per vehicle mile was 12 pounds, and the consumption of water per vehicle mile was $6\frac{1}{2}$ gallons, with a load 4·8 tons, and an average speed of six miles an hour, yet the makers of this machine now build a wagon to carry four tons, having a tare of four tons, which has been proved to be absolutely essential for successful working over long periods. Another difficulty that presents itself to makers of road wagons is the road itself. Unfortunately for the makers of motor wagons, there are a considerable number of roads in England by no means suitable for running road wagons on. It is a well-known fact that motor wagons, having a gross load of 10 tons, with two-thirds of this load

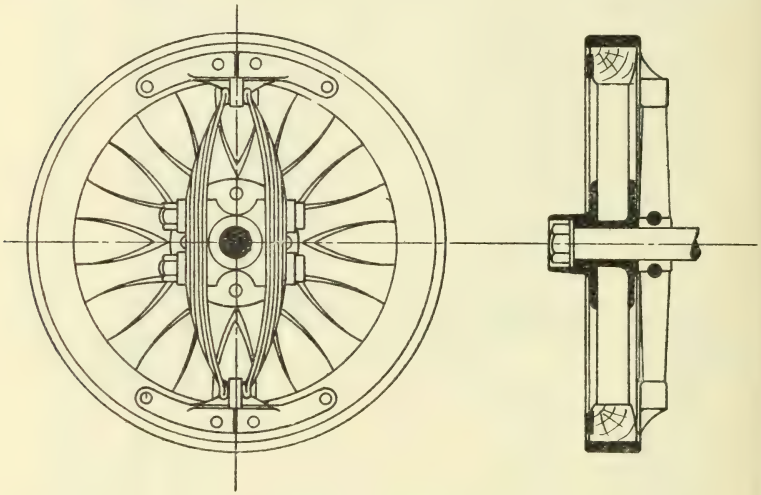


FIG. 8.

on the driving wheels, and having a total width of tyre of 20 inches, cause damage to some macadam roads. The damage becomes a very serious matter, and one that has to be considered by motor wagon builders. It is, therefore, evident that the pressure per square inch of tyre contact on a macadam surface must be too great. It is difficult to estimate exactly the economic value to a community of good roads, although it is universally admitted that there is a great advantage in having the public highways as perfect as possible. The maintenance of roads, therefore, becomes a matter of supreme importance, and a little consideration will show that a satisfactory solution of the problem is not to be found by chance, but requires

careful study, not only of local conditions, but of certain fundamental principles. The mutual action of roads and road vehicles ought to be studied for both paved and metal roads. In pavements, each

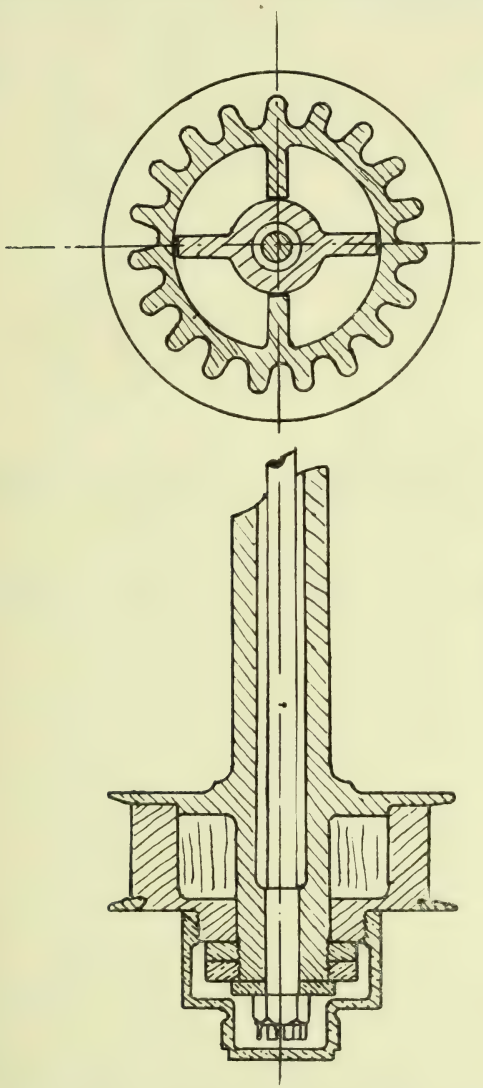


FIG. 9.

stone is of a shape individually to resist the weight of the wheel without any perceptible movement. On roads having a macadam surface the conditions are constantly changing. This is owing to

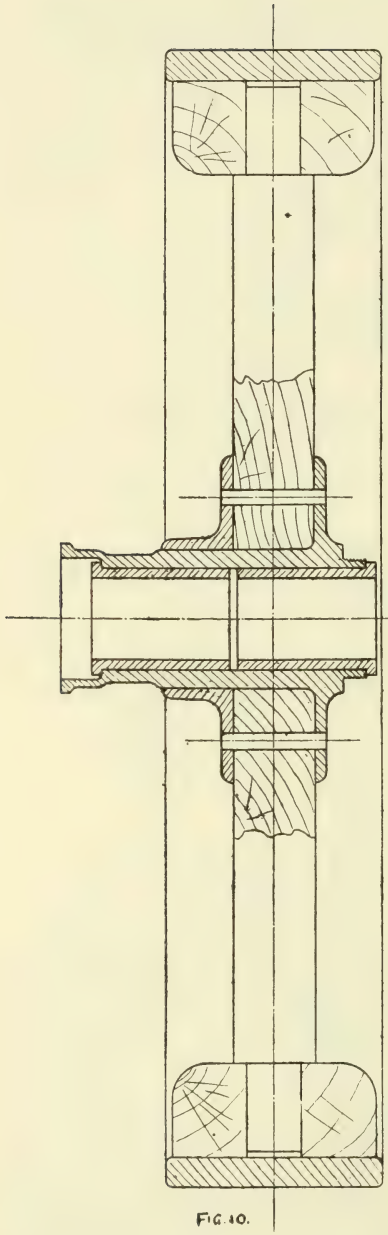


FIG. 10.

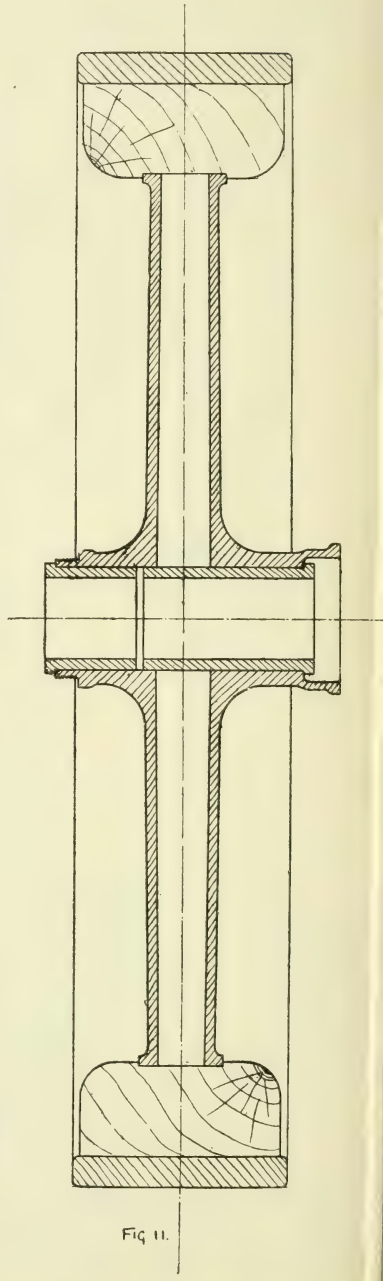


FIG 11.

mode of construction of the road, and the depth of the sand foundation, by which the pressure is spread over a large enough surface of the sub-soil to prevent any getting out of shape. However wet the weather may be, heavy motor traffic is unaffected on pavements. If, however, the pavement is badly kept up, so that its surface becomes irregular, whilst its paving stones become too rounded, in addition to the jolts and shocks which are so fatal to the preservation of the mechanism of the vehicle, the surface then constitutes a serious obstacle to heavy motor traffic. Although 20 inches total width of tyre for a gross of 10 tons is more than sufficient for a motor wagon working on good pavements, yet it is by no means sufficient when working on macadam surface. The result of numerous experiments has shown that to convey a gross load of 10 tons over roads having a macadam surface that tyres having 32 inches total width do not injure the road, but, on the contrary, improve the surface. Taking the best practice in steam road rollers, weighing 12 to 17 tons in working order, and assuming that two-thirds of the weight is on the driving wheels, that the pressure per inch width of tyre varies from 5 to 6½ cwts. Now, assuming that we have a wagon having a gross of 10 tons, with driving wheels 10 inches wide, and steering wheels 6 inches wide, and allowing two-thirds of the load to come on the driving wheels, we then get 6½ cwts. per inch of tyre. On roads having a macadam surface the conditions are constantly changing. The author has often noticed, when travelling with a gross of 10 tons at a speed of six miles an hour on setts, that the amount of steam required to keep up to six miles an hour was very, very small indeed. On the same road, where there has been a macadam surface, it was difficult to keep up a speed of four miles an hour with full steam on. Contrary to what has been said of the individual resistance of the setts which constitute a paved road, metal roads are composed of material of small dimensions, which are not able to resist the weight of heavy motor traffic by mutually helping one another. Again, the foundation and top layers together form a thickness or depth, which is oftener than not insufficient to prevent the sub-soil from having to bear so heavy a pressure that it gets out of shape. When rain has fallen for several days the binding material loses all cohesion, and the road becomes a mass of movable stones. At the same time the depths of the roads already too small, and still further reduced by the displacement of some of the stones, transmits to the sub-soil a pressure too great for its stability, and gives way. When this is the case, the roads

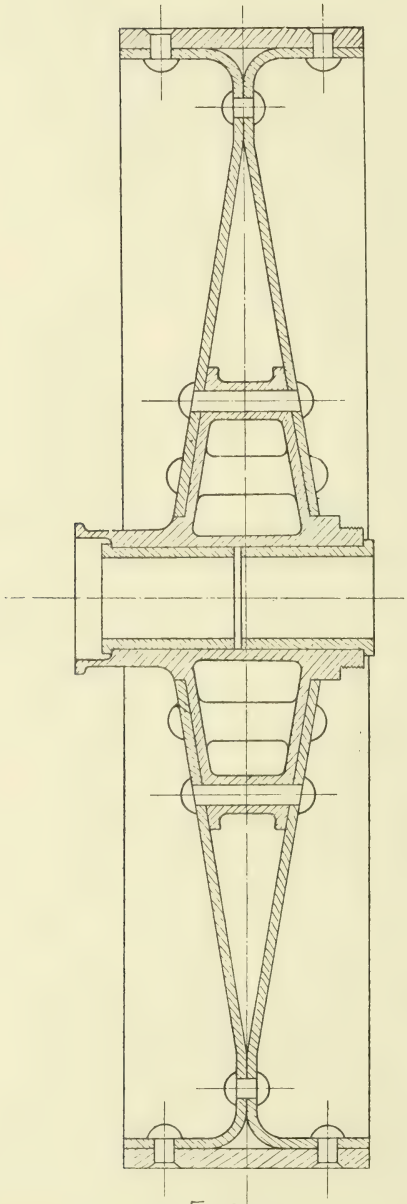


Fig 12.

continually present an inclined plane in front of the driving wheels, and this largely increases the rolling resistance. All engineers responsible for roads have agreed that during the rainy reason the rolling resistance may be trebled to what it is during fine weather.

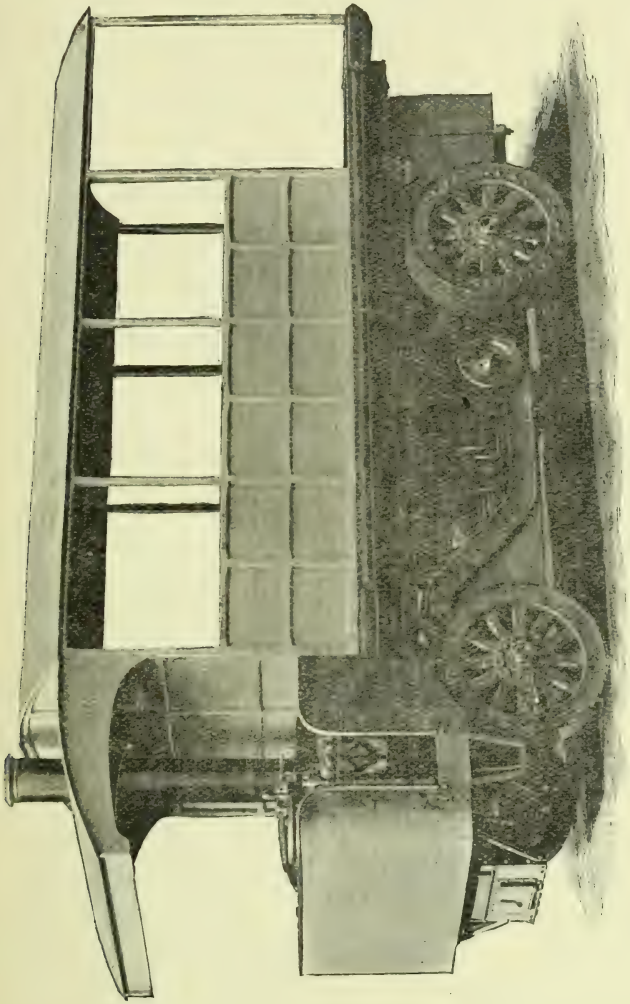
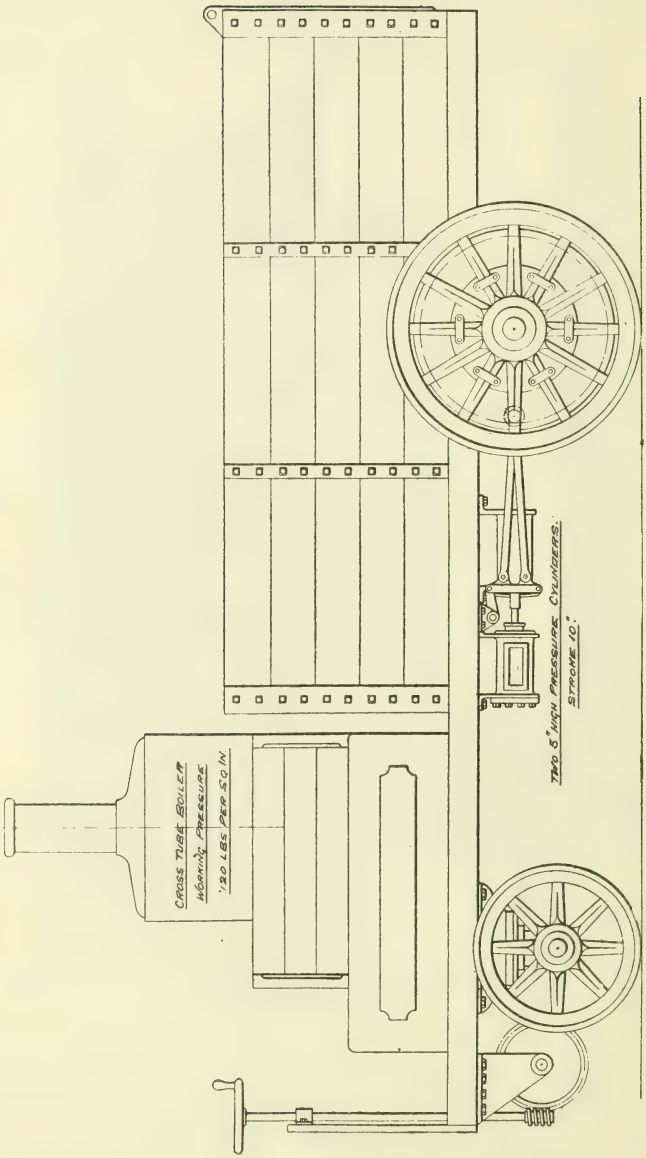
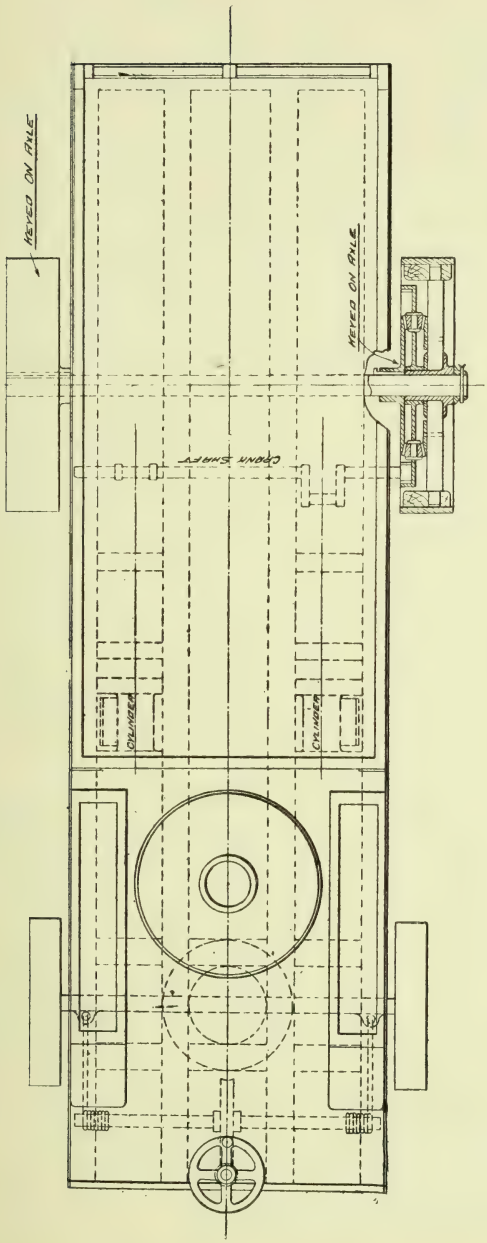


Fig. 13.

This is one of the most unfavourable conditions for mechanical propulsion, for it necessitates the motor not only being capable of a single maximum effort, but a continual one, which may be three times greater in wet weather than in fine, unless one is content to


CROSS TUBE BOILER
WORKING PRESSURE
120 LBS PER SQ IN
TWO 5" HIGH PRESSURE CYLINDERS.
STROKE 10."



SUMNER'S 5 TON STEAM MOTOR WAGON. A.D 1884.

TARE 5 TONS.

Fig 14.

diminish the speed. We have had a considerable amount of controversy lately on the speed of heavy motor wagons, and the amount of damage done by excessive speed. Unfortunately for the builders, the damage done is to the motor wagons. It is certainly marvellous how motor wagons hold together when travelling over setts at the speed they unfortunately are allowed to travel. The Light Locomotives Act stipulates a speed of five miles an hour, which under ordinary conditions is fast enough. But the author has many times seen motor wagons, having a gross weight of 10 tons, travelling more than nine miles an hour. Not a few skaters know that to stand too long on thin ice is a trifle dangerous, but to get across as quickly as possible means in most instances safety. And so it is when travelling over a bad road at a slow speed the "period" for sinking is increased as the speed is decreased. The author has many times been thankful that his firm's wagons were arranged so that the engine could be worked high pressure in both cylinders to enable the bad patch to be rushed. When travelling on a practically level macadam surface the speed of the wagon varies considerably, and on close examination it will be found that the depressions caused by the road wheels is constantly varying. The rut is apparently so slight that at the first blush one is inclined to give the matter no further consideration. To illustrate how very deceptive ruts are, the author has shown on Fig. 1, page 107, the gradients climbed by a wheel three feet diameter, and a wheel four feet diameter. The following table is instructive in showing, as it does, the effect of the various size of wheels and depths of ruts :—

Wheel diameter.	Gradient 1-inch rut.	Gradient 2-inch rut.	Gradient 3-inch rut.
2 feet 0 inches	20·7 per cent.	29·1 per cent.	37·5 per cent.
2 " 6 "	18 "	25·8 "	33·3 "
3 " 0 "	17 "	25 "	31·3 "
3 " 6 "	15 "	22·5 "	27·5 "
4 " 0 "	14·1 "	19·1 "	25 "
4 " 6 "	13·4 "	18·7 "	24 "
5 " 0 "	12·5 "	17·5 "	22·8 "

The following results of many experiments by several authorities is instructive, as indicating the tractive effort required under various conditions of surface :—

On Rails or Plates	5·16	pounds per ton.
Asphalt or Hard Wood	12·24	" "
Macadam	30·60	" "
Loose Gravel	140·200	" "
Sand	up to 400·	" "
Solid Rubber Tyres	60·	" "
Iron Wheels	60·	" "
Pneumatic	45·	" "

The author's firm have had a considerable amount of experience in various parts of the world, and have come to the conclusion that it is necessary to provide a lifting power on the driving tyres one-fifth of the total weight of the vehicle. They fixed on a gradient of 1 in 10, in addition to which they allow for constantly climbing a rut 1-inch deep, as on soft and muddy roads. According to the state of the roads and the diameter of the wheel, so does the curve "hump" itself to meet the load. The gradient incline added to the rut incline gives the total incline to be provided for. It is a case of providing a certain "dead lift" in the first place, and the B.H.P. is according to the rate at which the dead lift can be kept going. If we take the weight of the vehicle complete into the height it is lifted, in a given time, making, of course, a sufficient allowance for the exigencies and friction of the road, the whole thing can be worked out in foot-pounds per minute. A gear which is capable of forcing any practical hill would have to be equal to a theoretical lifting power of one-fifth of the vehicle. All these matters are, of course, relative, and not arbitrary. It entirely depends on the work to be performed. Assuming that we have a vehicle weighing 10 tons, and engine with a piston speed of 500 feet per minute, and a slow speed gear with a ratio of 28 to 1, giving a road speed of two miles per hour up a gradient of 1 in 10, and the gear and road friction, making it equal to 1 in 5. Total load to be lifted 10 tons, equals 22,400 pounds through one-tenth of two miles in 60 minutes, and to provide for doing 22,400 pounds through one-fifth of two miles in the time as regards piston area, though the gear would be acording to one-tenth of two miles. Here we have 22,400 pounds lifted :—

$$\frac{10{,}560 \text{ feet}}{5} = \frac{22{,}400 \text{ lbs.} \times 2{,}112 \text{ feet}}{60 \text{ minutes}} = 788{,}480 \text{ foot-lbs. per minute,}$$

$$\text{roughly} = \frac{788{,}480}{33{,}000} = \text{say } 24 \text{ H.P.}$$

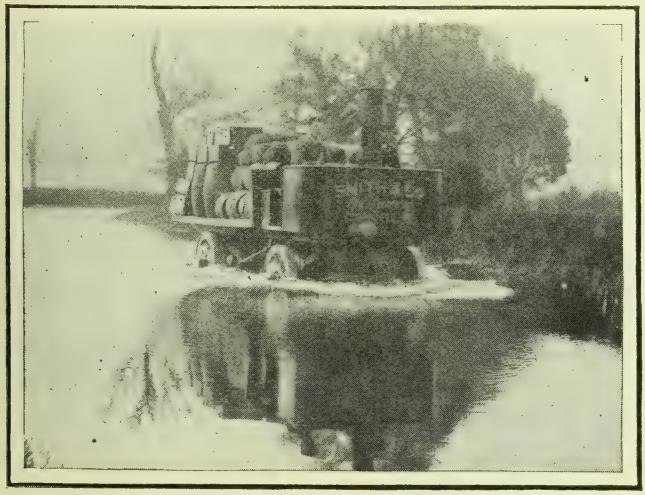
Referring to the three types, Fig. 2, page 107, shows the Thornycroft system. The boiler is of the central fired vertical water-tube type, see Fig. 5, page 109. Coke or coal is used as fuel. The engine is horizontal compound reversing, with a constant lead radial valve gear. Flat valves are used, arranged underneath the cylinders. The exhaust passes through a feed water heater, and is thence discharged into the smoke box. The transmission is of the Thornycroft chainless type. Two pinions of unequal diameters are mounted on the engine shaft, which alternately mesh with two spur wheels on the first portion of the counter

shaft. The counter shaft is in three separate parts, the middle portion being connected with the first and third by enclosed universal couplings. On a third portion of the second motion shaft is mounted a double helical pinion, which meshes with a spur ring borne on differential gear, which is carried by the rotating rear axles. The wheels are finally driven by this firm's well-known spring drive, see

The Lancashire Steam Motor Company's Standard Miller's Wagons.
FIG. 15.

Fig. 8, page 112. The engine runs at a normal speed of 440 revolutions per minute, which corresponds to a piston speed of 333 feet per minute. The ratios between the engine and road wheels are 10 to 1, and 18 to 1, which gives a road speed of $2\frac{1}{2}$ and 5 miles per hour. To change speed it is necessary for a driver to stop the engine, dismount and slide the required pinion into gear. A fly wheel is fitted on the engine shaft, which can be used for turning the engine shaft until the pinion is in line with the spur wheel.

Fig. 3, page 108, shows the Lancashire Steam Motor Company's system. The boiler is of the central fired vertical fire-tube type, see Fig. 6, page 110. Coke or coal used as fuel. The engine is horizontal compound reversing, fitted with piston valves in the small size. In the large size a modified Joy valve gear and flat balanced slide valves are used. The exhaust passes through a feed water heater, and is thence discharged into the smoke box. The transmission is of the "Leyland" double chain type. Two pinions of unequal diameters are mounted on the engine shaft, which alternately mesh with two spur wheels on the second motion shaft. On the centre of this shaft is a wide spur pinion, which is always in gear with the spur ring on the compensating gear. On each end of the compensating gear shaft are fitted two chain pinions, driving on to the chain rings of the road wheels. The engine reduction change speed and compensating gear are self-contained in the engine casing. The engine runs normally at 420 revolutions per minute. The ratios between the



A 4-ton "Leyland" Lorry Traversing a Flooded Road near Oundle.

FIG. 16.

engine and road wheels are 10 to 1, and 20 to 1, corresponding to a road speed of $2\frac{1}{2}$ and 5 miles per hour. The change of speed is effected without the driver dismounting, by sliding in a transverse direction the second motion shaft. The compensating gear is locked by means of a lever arranged underneath the frame. Since each chain is of sufficient strength to transmit the power required to take the load, in case of accident to a chain, the compensating gear can be locked, and the journey completed with one chain. A Cushion Drive, see Fig. 9, page 113, is fitted in the chain pinions. The steering is on the Ackermann system, and also the central pivot pattern. An arrangement for admitting "live" steam into both cylinders with independent exhaust is used.

Fig. 4, page 108, shows the Straker system. The boiler is of the central fired vertical water-tube type, see Fig. 7, page 111. The engine is horizontal compound reversing single eccentric. The transmission is of the single chain type. Two pinions of unequal diameters are mounted on the engine shaft, which alternately mesh with two spur wheels on the second motion shaft. The terminal drive from the second motion shaft to the "live" axle is by means of a single chain, which drives on to the compensating gear, one spur wheel on the compensating gear being secured to the "live" axle, and the other to the sleeve. The compensating gear is locked by inserting a pin through the road wheel boss. It is necessary for the driver to dismount to change speed.

BOILERS.

Unquestionably the boiler is the most difficult problem the motor wagon builder has to face. It does not by any means follow that a boiler that will give satisfaction for stationary purposes will be suitable for road vehicles. For stationary purposes "forcing" is of very rare occurrence, but on some roads the "Peak" must be met, many times in the course of an hour. It is well known that the power of any boiler, or, more accurately, the amount of steam which it can furnish in a given time, depends first of all upon its area of "effective" heating surface, and the amount of steam which a square foot of heating surface will produce varies between very wide limits, and is affected by a number of conditions. Of course the function of a boiler is to transfer as much as possible of the heat of combustion to the water contained in the boiler, and the heating surface is adapted to the same.

Referring to the very able report by the Judges of the 1901 Liverpool Trials, we find boilers giving the following results :—

Maker	Type of Boiler	Weights and Loads—Tons			Heating Surface Square Feet	Grate Area Sq. Feet.	Consumption of Fuel per hour in pounds	
		Tare	Average Load Carried	Gross			Per Sq. Feet of Heating Surface	Per Sq. Feet of Grate Area
Lancashire Steam Motor Co. B 1.	Vertical Fire Tube CentralFire	2·97	4·8	8·9	76	2·5	0·94	28·6
D 1.	Vertical Water Tube Central Fire	3·80	4·42	9·5	83	2·4	1·06	34.9
D 2.	Vertical Fire Tube Central Fire	3·7	4·48	9·6	77	2·75	1·24	34.9
D 4.	Loco. Fire Tube	3·98	4·4	9·7	51	2·5	2·37	48·5

Maker	Type of Boiler	Miles per hour (Average)	Consumption of Fuel (Coke) and Water per Vehicle Mile		Engine Cylinders × Stroke Inches	Steam Pressure (Average)	Declared Steam Pressure
			Water Gallons	Coke Pounds			
Lancashire Steam Motor Co. B 1.	Vertical Fire Tube Central Fire	6·04	6·5	12	$3\frac{1}{4}$ ins. by $6\frac{1}{2}$ ins. by 6 ins.	212	225
D 1.	Vertical Water Tube Central Fire	6·23	8·3	14	4 ins. by 7 ins. by 5 ins.	175·5	200
D 2.	Vertical Fire Tube Central Fire	5·68	10·2	16·9	$3\frac{3}{4}$ ins. by 7 ins. by 6 ins.	150·5	225
D 4.	Loco. Fire Tube	7·12	9·9	17	4 ins. by 6·4 ins. by 8 ins.	165·4	160

NOTE.—No account of the amount of fuel and water was taken for raising steam up to 180 pounds per square inch in arriving at the above figures.

Approximate Evaporative performances at 212 *degrees F.*

Type of Boiler	Fuel	Consumption of Oil per Gall. of Water	Consumption of Coke per Gall. of Water	Consumption of Coal (Welsh) per Gall. of Water
		Pounds	Pounds	Pounds
Vertical Fire Tube...	Petroleum	12	—	—
Vertical Fire Tube...	Coke ...	—	$5\frac{1}{2}$	$6\frac{1}{2}$
Vertical Fire Tube...	Coke ...	—	$6\frac{1}{2}$	8

Amongst the various boilers in use on steam road wagons the author will describe three of the most prominent types.

Fig. 5, page 109, shows the Thornycroft water-tube boiler. This boiler consists of an upper and lower chamber, connected by means of inclined tubes. The firing is done by means of a central opening in the upper drum. Referring to the drawing, it will be seen that the chimney is situated at a considerable distance from the centre of the boiler. Therefore, the tendency is for the products of combustion to pass through the tube spaces on the chimney side, and, it is therefore necessary to arrange a series of baffle plates to divert the direction of the products of combustion. A portion of the outer row of water tubes act as down comers. The regulation of the steam pressure is effected by means of a lid, which covers the central firing opening. To lower the steam pressure this lid is taken off the central opening, and a current of cold air is allowed to pass through this opening up the chimney. In the earliest pattern of this boiler the fuel came in contact with the lower portion of the tubes, which was a source of trouble. In the Thornycroft standard pattern of boiler, the fuel is well below the bottom of the tubes. This boiler was used in the 1899 and 1901 Liverpool Trials, and behaved very well.

Fig 6, page 110, shows a section of the Leyland central fired fire-tube boiler, introduced by this firm in 1900. It will be seen that this boiler consists of an upper and lower shell, jointed in the middle. The lower portion contains the fire box, to which is attached a central tube, connecting the fire-box crown to the upper tube plate, and is also used for stoking. Under ordinary working conditions there is 14 inches of water above the furnace crown. The fire tubes extend from the furnace crown to the top plate, the upper portion of the tubes passing through a brass casting, known as a steam drier.

The steam enters the drier opposite the steam outlet and therefore has to pass between the tube spaces, which effectually dries the steam on its way to the engine. In this boiler, as in most others, the products of combustion pass away to the chimney in the easiest direction, therefore, the tubes immediately under the chimney would do the most work if a baffle plate were not arranged slightly above these tubes. It is questionable if it is possible to construct any

FIG. 17.

One of the Lancashire Steam Motor Company's Tip Wagons delivering coal at the Preston Gas Works, and being loaded at the coal siding.

FIG. 18.

other pattern of boiler which will withstand such rough handling and maintain so steady a steam pressure as this class of boiler.

Fig. 7, page 111, shows a section of the Straker water-tube boiler, and is a modification of the De Dion, which ran in the 1899 Liverpool Trials. This boiler consists of two circular water drums, connected by means of short tubes. The fire-box is water jacketed. Inside the inner drum is formed a central shoot for stoking. A super-heater is arranged on the fire-box, above the fire bars. In this type of boiler, the smoke box temperature is exceedingly low, therefore it is difficult to prevent the exhaust steam from the engine showing.

Fig. 19.

WHEELS.

A common type of wheel used on steam road wagons is that known as the gun-carriage pattern, a section of which is shown at Fig. 10, page 114. It will be seen that this wheel is built up of felloes and spokes, terminating into a steel hub. In the early stages of the motor industry, we experienced some difficulty with this class of wheel, simply because we had no reliable data for this type of wheel when subjected to the severe everyday road conditions. We found that it was absolutely necessary to use English oak and ash, which had been seasoning for at least four years, two years in the open air. Great care is required in building up the wheel, and the periphery of the felloes must be turned, so that the tyre fits quite easy. The tyre, which is of weldless steel $1\frac{1}{8}$-inch thick, is subjected to varying

pressures in the hydraulic tyre machine. After the wheel has been tyred the centre is accurately bored to receive the hub. We have many instances of wagons running over four years and the woodwork still in good condition. The tyres, of course, require renewing after $1\frac{1}{2}$ to $2\frac{1}{2}$ years' work, according to the nature of the road. With chain driven wagons, where the chain ring support is attached to the

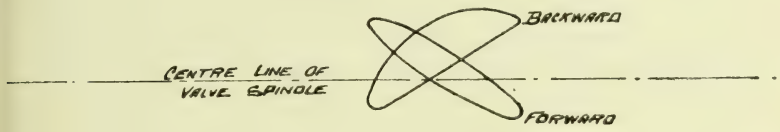


FIG. 20.
STEPHENSONS VALVE MOTION

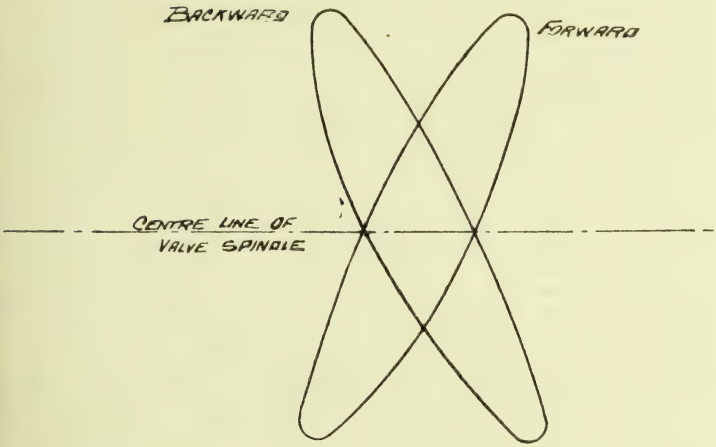


FIG 21.
LEYLAND VALVE MOTION

felloes, this attachment must be taken off when re-tyreing, the result being that the same bolt holes in the felloes cannot be used again. There are, of course, a number of loose parts to make up a gun-carriage wheel, and these require mathematical accuracy. It was with the object of getting over the number of loose parts, and also to obtain a better method of fixing the chain ring support, that led us

to design our composite wheel in 1891, which is shown at Fig. 11, page 114. This wheel consists of a steel casting, the periphery of which is fitted with felloes and the usual steel tyre. The object of arranging wood between the steel centre and the tyre, is that we shall have all the advantages of a gun-carriage wheel, while reducing the number of loose parts to a minimum, whilst we also obtain a much better arrangement for attaching the chain ring to the wheel, which is not interfered with when re-tyreing. Fig. 12, page 116, shows a very good pattern of steel disc wheel. The hub is fixed between two dished plates, and the chain ring drive is attached to the hub, between the spaces of the arms.

FLEXIBLE DRIVE.

It is well known that to start a vehicle from a state of rest, considerable strain is thrown on the engine and gearing, unless some provision is made to take up the shock. In the Thornycroft system (see Fig. 8, page 112), two laminated springs are used on each of the driving wheels, and since the driving wheels are not secure to the "live" axle, the axle is allowed to turn round, due to the amount of compressibility in the spring, before giving motion to the driving wheels. This arrangement was first used by Messrs. Thornycroft in the 1899 Liverpool Trials, and has been Messrs. Thornycroft's standard practice since. In the Thornycroft system the shock is taken up on the terminal drive, this being the "live" axle, on to which is fitted the compensating gear. Another system is that known as the Leyland (see Fig. 9, page 113). By referring to Fig. 3, page 108, it will be seen that the Leyland transmission is by means of gearing from the engine shaft to the second motion shaft. On this shaft is fitted a pinion, gearing with the differential shaft. On the end of this shaft, which is divided, are fitted two chain pinions. By referring to Fig. 9, page 113, it will be seen that the flexible drive is obtained by arranging four specially prepared rubber blocks in each of the chain pinions. On the chain pinion ring are two wings, and on the shaft also are two wings. The action is as follows:—The transmission having reached the compensating gear shaft, and the terminal drive leading from this shaft to the road wheels being by means of chains, it therefore follows that since the drive from the engine to the compensating gear shaft is rigid, and the resistance offered by the road wheels is great, then the compensating gear shaft wings will compress the rubber according to the amount of load on the wagon.

Again, referring, in conclusion, to the 1896 Light Locomotives Act, which does not admit of building a steam road wagon to carry a load of four tons with anything like a reasonable "life," the low factor of safety, varying conditions of the road, speeds varying from 50 to 75 per cent. greater than stipulated, over-loading, and the difficulty of obtaining reliable drivers in this early stage of a new industry, are matters which are of paramount importance. It is argued by some, that chains are unreliable. The author's ten years' experience in the motor industry has proved to him that chains should not be too readily thrown over. Makers of high powered petrol cars have alternated between chain and gear driven with powers up to 100 H.P., and the most successful results have been achieved by chain driven cars.

DISCUSSION.

Mr. Holt

Mr. ALFRED HOLT said—I do not know that I can say anything worth hearing, my only excuse for speaking at all is that this is a subject I have followed for a very long time.

If motor vehicles are to come into practical use they must conform to the same requirements as other vehicles. These are many, perhaps the most onerous one is that they must be able to wait the length of time that is necessary for loading and discharging; if they cannot do this then, viewed from the commercial standpoint, they will not be used.

The fault of the motor vehicle is that the motor and the vehicle cannot be separated, as can be done in the case of a horse and lorry.

I believe long experience has proved that there is no vehicle so convenient for the purpose of conveying goods as the Liverpool lorry. You can take the horses from the vehicle, and if, for instance, you are loading on the dock quays, you can draw a number of lorries into the shed and as soon as the horses are taken away, let them be loaded, then bring the horses back again and draw them out, one team of horses attending to six or eight lorries, remove them to the metals and then by mechanical traction carry them anywhere about the country in trains.

I think the motor and vehicle being in one is the leading condemnation of the motor system. It must be ten years since I first heard in this very room motor vehicles advanced as the thing of the future, and I hardly see any of them in use yet, and those that are are mostly in the hands of those who are using other people's money and not their own.

After a good deal of thought and constant observation I do not think you can make motor traction a commercial success. It is, of course, a most interesting engineering problem, but after all, we have to abide by the commercial test. I apologise for introducing this view of the subject, but it is clear you must be governed by the commercial possibility—that which will pay, and though I hope I am wrong, I do not think the motor vehicle seems to promise that.

The *vehicle*, it may be noticed, is perhaps always cheap, and the *motor* costly. The ordinary Liverpool lorry is worth about £60 and the horses about £120. In the motor vehicle, the part that carries

the goods is of small value, whilst the engine which moves them is the opposite. I don't know exactly what a Liverpool motor lorry would cost, probably £600 to £700. If it has to wait several hours for loading or discharging the waste is apparent. Moreover, you have to pay the wages of a more expensive man than a mere carter. Thus, both in capital and working, the cost comes very near to damning the account. Mr. Holt

Also, and this is a very important point, I question whether you can make any vehicle successful which depends for its progress solely on the friction of the wheels on the ordinary road. There are many places in Liverpool where a loaded motor vehicle would not travel by merely making its wheels revolve, an extraneous force is necessary.

Mr. JOHN A. BRODIE said—When the Self-propelled Traffic Association was started I was rather more enthusiastic about motor wagons than Mr. Holt was, and I am still of opinion that they will be found of service for many purposes. To-day I am more convinced than ever that the principle of Mr. Holt's plateway is right where large quantities of goods has to be dealt with, and that sooner or later developments somewhat on his lines will take place, and from this point of view the train exhibited at the Paris show is interesting, because the motor carried powerful machinery and the power was transmitted through a line of shafting to the hub of the driving wheels of each of the vehicles comprising the train. Mr. J. A. Brodie

I have now had some little experience with motor vehicles, and, principally owing to the tare limit, have had troubles which were sometimes not easy to overcome, but to-day we are coming out about right as regards cost of working. We work from 4 o'clock in the morning to 12 o'clock at night. Each wagon brings in a total of 40 tons per day over an average distance of between two and three miles, and they are charged out at the corresponding cost of horse haulage.

The most interesting part of the wagon to me is undoubtedly the wheel. And I believe that when the motor manufacturers can produce a satisfactory and economical wheel suitable for the different classes of road surface, the motor wagon will become an economical vehicle for many classes of traffic. I do not, however, know of a completely satisfactory wheel, and I would be very glad to hear the experience of any of the gentlemen present.

For the purpose of quietening the motor wagons my Committee decided to try rubber tyred wheels, and it was immediately noticed that from the time the rubber wheels were put on, the expense of

Mr. J. A. Brodie maintenance came down surprisingly. Unfortunately, the rubber did not last long enough to be economical, but it served to show that a resilient wheel would be of great advantage in many ways.

Mr. Nixon Mr. C. B. Nixon said—I did not expect to be called upon to speak this evening, but as I am gaining experience by running eight of these wagons, I may offer one or two remarks on the subject.

The three ton tare weight has been dragged forward from time to time to excuse the commercial failure of the earlier wagons. This was no doubt the primary reason, and is still the great hindrance to the development of the industry. I think, however, there were other reasons, and one of these was the great amount of unsuitable material which these earlier vehicles contained, and their heavy design. A second reason was the inadequacy of the auxiliary machinery; in the early days my company lost a total of hours running into months from the failures of feed pumps. This particular difficulty is got over by using injectors.

There are two or three other points which are calling for attention: one, as Mr. Brodie has just said, is the driving wheel, and another is the valve gear, or to be more exact, the valves themselves. Piston valves are used generally; these are very tight and give excellent results for the first two or three hundred miles, but after that begin to blow through. I consider that the energy lost would be less if ordinary slide valves were fitted when the temperature of the steam is that due to a pressure of 225 pounds, reserving piston valves for use when the steam is considerably superheated. It is well to remember that marine practice is to fit piston valves to the high pressure and slide valves to the low pressure cylinders. Excepting the flash boiler type, there are only two or three makes of lorry using superheated steam, and the best known of these is the Straker. As far as valve gear is concerned there appears to be no reason why the Stephenson link type should not continue to give satisfactory results.

The author says that the length of stroke should be increased, also the diameter of the wheels; both proposals I think most desirable. For the work of my firm we find the maximum diameter to be 3 feet 9 inches, *i.e.*, when the lorry is about 6 feet 6 inches wide; if you go beyond this the platform becomes inconveniently high for unloading by hand.

Mr. Rosenheim Mr. E. A. Rosenheim said—There are just one or two remarks I should like to make, principally in connection with the wheel and tare questions. All the existing types of wheel are faulty and of bad design, although they are the best of their type that can be obtained.

Mr. Rosenheim

What is absolutely essential to make motor vehicles a commercial success is to obtain some form of resilient tyre which will lessen the excessive vibration set up over rough and paved roads.

Again, in the majority of heavy motor vehicles, one suffers very great disadvantages owing to the three ton tare limit.

There is no doubt that certain material has been used in their construction in the past which has in practice been proved to be unsuitable, but this is inevitable in every new industry and has all been overcome by practice and the experience gained in running. Experience has shown that it is impossible to build a commercial vehicle to come in under the three ton tare, and if these vehicles are going to be used commercially they will have to be made so that they can be run on a paying basis. To do this it is necessary to have a load which will average about seven tons. Well, it is impossible to carry a seven ton load with a vehicle tareing less than five tons. Otherwise the breakdowns will be excessive.

I must apologise for dilating thus on the tare question, about which so much has been said, but this is a point of vital consequence to the whole motor industry, and its commercial importance cannot be over-estimated.

The author points out in these engines that the common practice is to run them at a speed of 600 feet per minute; this I consider bad practice and a common fault. A man may be out very late at night and anxious to get home, and he over-drives his engine, with the result that the engine is run at twelve miles an hour instead of six miles. Normally, this means roughly that we have a piston speed of (say) anything from 1000 to 1100 feet per minute and resulting breakdown. A remedy might be suggested (say) by governing the engine and so design same to run at a sensible normal piston speed with a fair percentage allowance for overload, after which the governor would immediately come into action.

A great point which I think should be borne in mind, is that it is unimportant what the total tare may be provided that sufficient width of tyre is used to distribute this weight, and I see no reason why a total moving weight of 15 tons should not be propelled with safety to the roads, provided that a sufficient width of tyre is adopted. If this width is not provided, of course damage will result and the machine will sink through the crust even on good roads. Of course, with the existing three ton tare, it is impossible to have a machine which is adequately tyred.

To revert to the author's gradient diagram. I cannot quite agree

Mr. Rosenheim with him when he speaks of the car going up a gradient of 1 in 10 and climbing a rut one inch deep in the road surface.

Of course only one wheel may be in this position, and I think it is hardly fair to say that the engine power would have to be increased in direct proportion to this increase of gradient. If the author assumes that the vehicle starts initially up the grade from rest he is right, but if not, he allows nothing in his calculation of power required for the momentum which the machine doubtlessly would have.

Of course some sort of allowance ought to be made, there is no doubt, but I think the chief point in proportioning a machine to climb gradients is to so distribute your weight as to get enough adhesion with the driving wheels. Take, for instance, the case of motor wagons trying to climb a gradient (say) like William Brown Street on a greasy day; on a dry day they can run up very easily, but when the sets are greasy they experience great difficulty, and therefore in the design of the machine it is the varying surfaces and conditions of the roads which it will have to traverse that must be taken into consideration, and not so much the gradient.

A very slight gradient in greasy weather will offer more difficulties to a wagon than a 1 in 8 gradient in dry weather, and the engine must be designed, and the weight so distributed, that you get the sufficient amount of adhesion on your driving wheels on your theoretically worst type of road.

Mr. Kenyon Mr. George C. Kenyon said—What I am about to say may be "quibbling." I do not pretend to know much about motor vehicles, but I have had a little experience of them on the Mersey Dock Estate, where we have, I think, four motor wagons, and they bring a good deal of heavy materials on to the new dock works. Well, there, of course, we don't have nicely paved roads, but the difficulty appears to be in the wheels slipping and the wagons becoming stuck. Only to-day, a gentleman came rushing into my private room, exclaiming, "Have you got a camera?" "Why, what's the matter?" I asked. "There are twenty horses trying to shift a motor wagon," he said. I think this was rather a coincidence in view of the subject of the paper to-night.

Not very long ago, on the Mersey Dock Estate, a motor vehicle was drawing a trailer with a heavy load of timber and the trailer got in the wrong position. They wanted to back the trailer away by means of the motor but could not do so. Eventually, they had to discharge the load, drag the trailer away by means of horses, and then the motor was all right. But that was on broken ground and under extraordinary circumstances, I suppose.

Mr. Douglas Mackenzie said—I think I ought to explain, first of all, that what interests me in this subject is that my business in London is to run these vehicles for the purpose of making them pay. We are doing it solely from that point of view. Mr. Mackenzie

In the first instance we set to work with these motor vehicles and devoted six months to buying experience. We obtained vehicles of different types, put them to work, and tabulated the results. I may say that we find now that there is a great deal of work in London that can be done at a living wage, but we have had to have vehicles built to a special specification to enable its being done successfully.

Mr. Holt mentioned that he thought the great failure of motor vehicles was the difficulty of uncoupling the motor from its load. In London, we have what we call "young traction engines." We use them for bringing up the market garden produce, as it is impossible to take a motor wagon or tractor off the hard road. Horses have to be employed for the loading up of the wagons, which latter are drawn out on to the road, and about six o'clock in the evening a young traction engine takes charge of a vehicle and runs it up to Covent Garden market, and then runs back for a second one.

I should like to criticise what the author says as to damage to macadam roads. He says, "It is a well-known fact that motor wagons, "having a gross load of 10 tons on 20 inches total width of tyre, cause "damage to macadam roads." Well, there are macadam roads and macadam roads, but if they are made with proper foundations and well consolidated by steam rollers, there is no doubt they will carry car loads of 10 tons per axle on a 20-inch tyre width. On the other hand, if you take a lorry drawn by five horses, the latter will dig their feet into the road and cause damage.

Some time ago I carried out some experiments. I had a traction engine weighing 16 tons, pulling three wagons with a tare of 3 tons 5 cwt., and carrying a load of 9 tons 8 cwt. We had practically $12\frac{3}{4}$ tons on the wagons and 16 tons on the engine. The engine driving wheels carried considerably more than two-thirds of the engine weight, I should say they carried 12 tons out of the 16 tons. Now we ran these on soft roads and they sank in to a depth of three-quarters of an inch, and in the case of the trailing wagons to a depth of $1\frac{1}{2}$ inches. It is therefore obvious that an increased diameter is more effective than an increased width in preventing damage to the roads.

I consider that, as soon as the new Local Government Board regulation to allow a width of 7 feet 2 inches is approved, we ought to start to use 4 feet, 5 feet or even 6 feet driving wheels. We shall

Mr. Mackenzie then find we shall avoid risk of damage to the roads and we shall find it easier work and have less wear and tear on our vehicles.

With regard to the wheels which the author speaks of, I have had a great deal of trouble myself, but I have a lot of experimental wheels in hand, and I am hoping in the course of this year to be able to prepare a paper giving the results of their work.

The most satisfactory wheel I have found is one called "Stagg's patent." Instead of the hub shown on the blackboard there is a hub of cast steel and the wooden spokes are fitted into it, but the sockets in which they are driven are tapered, and on the back side of the hub is a rubber pad. When you tighten up the hub the effect is to push the spoke outwards and to tighten it against the felloe and against the tyre.

A great deal has been said—and very justly—as to the necessity of a resilient tyre. I have tried experiments myself in that direction. I find that rubber is too expensive, and that the steel tyre has the disadvantage of noise and want of grip on greasy roads, and I have come to the conclusion that the only tyre which will meet the case is the wooden tyre. They are in use on traction engines. There is one working in Bolton that has been at work two years and has proved extremely successful. I am having several sets fixed, and I am certain that a semi-resilient tyre, as this wooden tyre will be, will save the wheel and wagon a great deal.

Mr. Rosenheim Mr. A. E. Rosenheim said—I should just like to say that I have had three experimental wheels sets of wooden tyres made and tested with very poor results. When I tried soft wood I found they lasted two days. With hard wood, such as greenheart and elm, they only lasted one day in each case. These wheels were run entirely on the Liverpool Dock and Liverpool and St. Helens Roads, and as an interesting point it may be noted that with the soft wood, skidding on the greasiest road was entirely overcome, but on the contrary with the hard wood wheels the machine skidded worse than with ordinary steel tyres.

Mr. Norris Mr. W. Norris, in reply, said—Referring to Mr. Holt's remarks, I recognised, in preparing my paper, that owing to the comprehensive term "Motor Vehicles," which embrace so many types, including those actuated by motors of the internal combustion variety, that I must confine myself to only a small portion of the subject. I therefore mentioned three of the types of steam driven most economically used. There is, however, as Mr. Alfred Holt points out, a very large field for a motor independent of the vehicle for carrying

the load, which would in many instances minimise the considerable loss of time involved in waiting for the load. My firm recognise that there is an opening for an independent motor, and in 1901 designed such a motor, commonly known as a tractor, but to the present time have not been successful in convincing motor wagon users of their utility. The type of tractor my firm consider to be the most useful for dock work and goods yards is one arranged with a vertical boiler arranged behind the front axle, the engine and transmission gear underneath the frame, the water tank on the top of the frame, the steering wheels on a central pivot, so that almost any degree of lock can be obtained. The driving wheels are of large diameter. There is also a crane arranged, which is operated by the engine. The great advantage of the tractor is, that the ordinary horse drawn lorry can be used as a trailer, and whilst being loaded the tractor could be employed performing other duties, such as hauling already loaded lorries to their destination. Mr. Norris

I cannot agree with Mr. Holt as to the cost of working motor vehicles compared with horse drawn vehicles. We have a considerable number of instances where users of our wagons have informed us that there is a very great saving indeed. I will not, however, give an instance of a wagon working with full loads both ways, but will refer to a wagon working between the Preston docks and Messrs. Ley's corn mill, a maximum distance of 3 miles, the majority of the journeys being not more than 1½ miles, over probably one of the worst roads in Lancashire, the "wait" at the docks being a considerable item. I have ascertained from Messrs. Ley the following:—

From January 1st to April 30th, 1903.

Total tons carried	2526
Total miles loaded	1211½
Total ton miles	6954½
Possible working days	86
Possible working half-days (Saturdays)	17
Actual working days	84
Actual working half-days (Saturdays)	14
Total miles empty	675½
Average ton miles per day	76·4
Average miles including full and half days	20·4
Maximum load carried	50 sacks of 240 pounds each

Mr. Norris

MOTOR	HORSES.
Ordinary day's work—	Ordinary day's work—
From 6-30 a.m. to 5-30 p.m.	From 7 a.m. to 6 p.m.
90 Packs of 240 pounds Meal. From Walton to John Street, Preston. 1½ miles.	Two Horses, wagon and man. 30 Packs 240 pounds Meal. From Walton to John Street, Preston. 1½ miles.
Empty from John Street to Dock.	Empty from John Street to Dock. 1 mile.
200 Packs of 240 pounds Corn. From Dock to Walton. 3½ miles.	75 Packs of 240 pounds Corn. From Dock to Walton. 3½ miles.
Five days per week. Half-day for cleaning, &c.	Five days per week. Half-day for shoeing, &c.
	The above, if hired, costs 15s. per day, which is equal to 1d. per pack, Walton to John Street, and 2d. per pack, Dock to Walton.
	The first cost must be reckoned as less than this to allow for the carter's profit.
Cost per week of carting with Motor—£5 10s 0d.	Six Horses, three wagons and three men will cart from 20 to 30 packs per day more than Motor from Dock to Walton.
	Cost per week of carting with horses, if hired, the same quantity as the Motor wagon carries.—£10 4s. 2d.

Estimated Annual Expenditure. Based on 260 *Working Days.*

Prime cost, £550.

Depreciation at 10 per cent. on £550	£55 0 0
Interest on capital outlay at 5 per cent.	27 10 0
Driver at 30s. per week	78 0 0
Coke at 12s. per ton—1 ton per week	32 10 0
Water, lubricants and sundries	20 0 0
Repairs and adjustments	50 0 0
	£263 0 0

Working days :—260.

Ton miles :—22,920.

Work done :—3·7 tons × 20·4 miles × 300 days = 22,641 net ton miles per annum.

Cost :—£263 + 22,644 = 2·73d. per ton mile. (Say 2¾d.)

With regard to what Mr. John A. Brodie said, as he very ably pointed out, the noise caused by motor wagons is of great importance, and should be taken into very serious consideration by builders of motor wagons. Wheels of the gun-carriage pattern run for a considerable time without giving trouble, providing the spokes and felloes are well seasoned, and the tyre is not less than $1\frac{1}{8}$-inch thick for a wagon with driving wheels having $3\frac{1}{4}$ tons on each wheel. If the wood is not well seasoned then there is the natural shrinkage. As already pointed out, we have found the most satisfactory type of wheel to be our composite pattern. Of course the noise is not reduced by using this wheel. We have made a number of experiments with wheels having a composite tyre, using various brands of wood endways and crossways of the grain, and have every reason to believe that the results of our experiments will be successful in reducing the noise, which is a very serious consideration for municipal work, especially when travelling over sets at high speeds.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

SPECIAL MEETING—20TH JANUARY, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

VOLTAGE REGULATION IN ALTERNATING CURRENT SYSTEMS.

BY H. S. MEYER.

A POINT of great importance in all electrical installations supplying light and power, is the voltage regulation with varying load. While in direct current systems the problem is comparatively simple and has been completely solved by the use of compound wound generators, in alternating current work this question is of a more complex nature, since the phase relation between current and E.M.F. has to be considered. It is intended to give in the following paper a general review of some of the most important points connected with the subject of voltage regulation in alternating current systems, without, however, entering upon a detailed consideration of the theoretical side, which has been treated by various writers with a clearness which it would be difficult to surpass.

The discussion of the theme will be divided into :—

(A) Inherent Regulation of Generators.

(B) Influence of (A) on the system.

(C) Automatic Voltage Regulation and Compounding.

(A) INHERENT REGULATION OF GENERATORS.

1.—*Method of specifying Regulation.*—

In common with the custom on the Continent and in America, the inherent regulation should be standardized as referring to the percentage increase in the terminal voltage when full load is taken off the machine, the excitation remaining unaltered, and due allowance being made for variations in speed as caused by the engine regulation. The second method of specifying the inherent regulation, which one finds often used by consulting engineers in this country, refers to the percentage fall in voltage upon throwing on full load, keeping speed and no load excitation constant. This, as will be shown later (see Table II), leads to entirely different figures, and should be abandoned so as to conform with the practice of the rest of the world.

2.—*Influence of the Regulation on the Design of Alternators.*—

To be able to specify in each case the most economical value for the regulation, it is necessary to consider the influence which this factor has on the size and cost on the efficiency and operation of this class of machines.

Broadly speaking, the economy of an alternator design for a given frequency and speed is governed by two laws :—

(1) The output is directly proportional to the armature ampere turns times the magnetic flux, or, in other words, the output of a given carcass, assuming equal specific use of the materials, can be increased directly as the increase in armature ampere turns.

(2) The cost of a design varies almost as the square of the variation in the air gap diameter. Therefore, this should be just big enough to accommodate the poles and the exciting winding, giving at the same time due consideration to the question of ventilation, and to the mechanical difficulties introduced by an excessive width of the machine.

Against these requirements for minimum cost and maximum efficiency, one had to consider those determining the regulation of a machine. These may be expressed as follows :—

(1) The ratio of $\frac{\text{field ampere turns}}{\text{armature ampere turns}}$ should be large.

(2) The self-induction and ohmic drop of the armature should be low.

(3) The magnetic leakage between poles should be small.

(4) The magnetic densities in the poles should be high.

(5) The flux distribution should be such as to produce a sine wave.

(1) To satisfy the first point, which has the most decisive bearing on the quality of the regulation, it is necessary either to choose a small number of armature ampere turns, or a large number of field ampere turns. The former conflicts with the first law, since by reducing the turns on the armature the flux has to be increased so as to obtain the desired output; but to carry the larger flux, the material—both iron and copper—must also be increased, the latter due to the longer mean length of turn in stator and rotor. An increase in field ampere turns will be against the second law, as it will always mean an increase in the diameter of the revolving field so as to gain the necessary room for the increased field copper. In actual practice, the designer will have to compromise between both these possibilities whenever a close regulation is required. Here it may be of interest to mention the case of alternators direct connected to steam turbines, where the diameter of the rotating field is once for all fixed by the allowable peripheral speed, and where the machines for this very reason already obtain a great length. To build such machines economically with a very close regulation is extremely difficult if not impossible.

The number of field ampere turns is almost entirely dependent on the length of the air gap, and therefore a long air gap is essential for close regulating machines. An illustration of these points is given in Table III.

(2) While a reduced number of armature or back ampere turns will improve the regulation by weakening the magnetic field of the armature, which tends to counteract the efforts of the main field, a low armature self-induction will further help in this direction by reducing the inductive drop due to the alternating currents flowing in the armature conductors. To obtain a low armature self-induction, the winding has to be properly sub-divided and so arranged that at the same time the effect of the end connections is minimized, which is of importance particularly in machines having a large polepitch and a small width. However, in modern alternators the influence of self-induction on the regulation is only about $\frac{1}{4}$-th to $\frac{1}{5}$-th as large as the influence of the back ampere turns.

The ohmic drop in modern designs is usually small, due to the heating requirements of the machine lying between $\frac{1}{2}$ per cent. and $1\frac{1}{2}$ per cent. of the out-put, and it would hardly be economical to try to improve the regulation by a further reduction of this quantity.

(3) The leakage between poles should be as small as possible. To obtain this condition, one has to choose short poles, a large pole

pitch and the pole arc in maximum 66 per cent. of the pitch—although these requirements lead to a larger diameter and consequently to a more expensive design. The leakage coefficient is further governed by the length of the air gap, and the iron densities in the machine, and increases with the load in about the same proportion as the excitation. The following Table gives some average values for the leakage coefficient at no load in dependence on the diameter per pole for normal machines designed for about 7 per cent. full non-inductive regulation and moderately saturated :—

TABLE I.

Diameter per pole	...	Leakage Coefficient
2-inch	...	1·4
3 "	...	1·35
4 "	...	1·3
5 "	...	1·26
6 "	...	1·22
7 "	...	1·18
8 "	...	1·16

(4) The magnetic densities in the poles should be high, so as to introduce a saturated part in the magnetic path, which will limit the rise in voltage when the load is taken off the machine. Densities of 110,000 to 115,000 lines per square inch are here quite allowable, provided the designer knows exactly the leakage coefficient of his machine and the quality of his material; but even then it is dangerous for machines which have to work on a low power factor, since the leakage factor and its change with the load introduces an uncertain quantity, and a small error in this direction may bring one to a part of the saturation curve where a small change in the voltage corresponds to an enormous increase in the excitation; or in other words, to keep in such cases the terminal voltage at its normal value when working at a low power factor would require an excessive exciting current, and thereby causes dangerous heating of the field winding.

For the above reason it is advisable to differentiate between machines which are intended to work on unity power factor, or on a power factor say not below ·90—and those intended to work chiefly on a low power factor. In the latter case it would be better to use lower densities than mentioned above—although this leads to a more costly design.

(5) All parts in the machine should be so proportioned that the resultant wave shape of E.M.F. and current resembles as closely

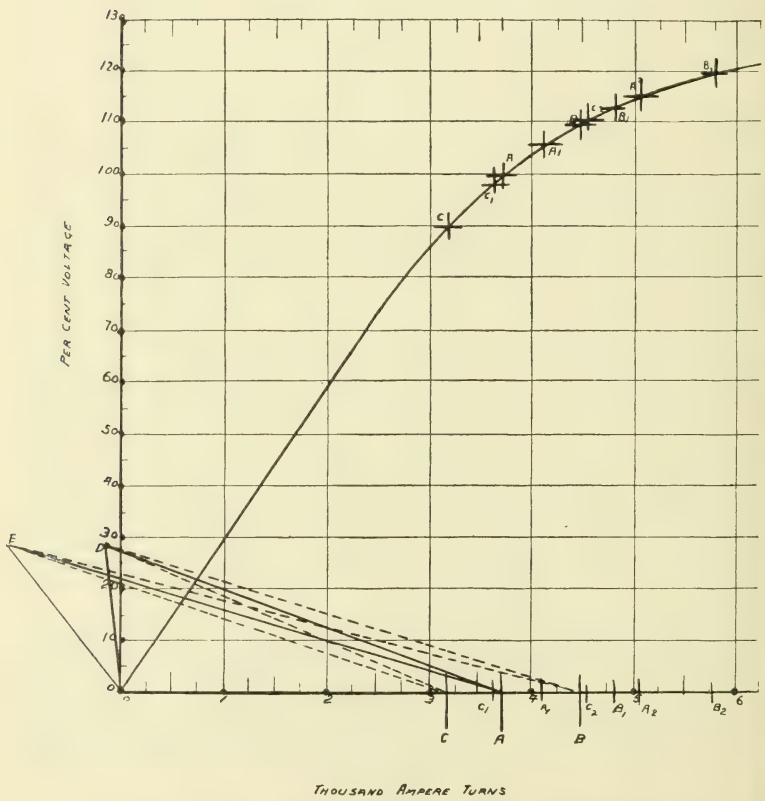
as possible a sine wave. While this is desirable from a general point of view, it will also be favourable towards regulation, since an inductive circuit will have less harmful influence than with a complex wave form.

To illustrate more in detail some of the above points, the following figures and tables have been prepared. In Fig. 1 a well-known graphical representation is made use of.

FIG. I

SATURATION CURVE

% VOLTS	100% POWER	80% P. F
100	$a_1 = 6\%$	$a_2 = 15\%$
110	$b_1 = 3\%$	$b_2 = 7\%$
90	$c_1 = 10\%$	$c_2 = 23\%$



ERRATA.—Point B on above curve should be on 110 curve, and C_2 slightly above it.

Here OA represents in magnitude and direction the resultant amp. turns of the field and armature ; OF, 90 degrees displaced from this, represents the direction of the induced E.M.F., whilst the magnitude is represented by the saturation curve. OD and OE represents in direction the generator current on 100 per cent. and 80 per cent. power factor respectively. The magnetising force of these currents is in phase with them, and therefore OD and OE can represent the amp. turns of the armature both in direction and magnitude. (As a matter of fact, OD and OE are rather larger than the actual value of the amp. turns to take in the effect of self-induction and ohmic drop of the armature winding ; it will also be noticed that OD is not exactly in phase with OF as the self-inductive E.M.F. of the winding tends to throw the terminal voltage slightly behind the induced voltage.) The field amp. turns are represented in magnitude and direction by AD and AE. The value of the field amp. turns must be so large that with any given value and phase of line current the resultant OA is such as to give the required voltage Aa as taken from the saturation curve. This is the condition at any particular load, say full load. If the load is thrown off, the points D and E coincide with O, and consequently if the field current remains unchanged, the points A will move out to A^1 and A^2 respectively. From the saturation curve we find that the corresponding voltages are A^1 a^1 and A^2 a^2. It will be seen from the figure that the regulation depends on the ratio of AD to AO, that is, on the ratio of OD or OE to OA, or in words, on the ratio of the armature ampere turns to the no-load field ampere turns, and further on the flatness of the saturation curve at normal voltage. In the figure the same construction is shown for points 10 per cent. above and 10 per cent. below normal voltage, so as to illustrate the influence of saturation. The actual values obtained for the regulation are given on Fig. 1, while Table II. gives for the different points the per cent. increase in the excitation necessary to keep the voltage constant from no load to full load.

TABLE II.

Per cent. increase excitation from no-load.

	To full non-induction load.	...	To full load 80 per cent. P.F.
(A)	10·8	...	36·5
(B)	7·9	...	29·2
(C)	14·3	...	43·5

The saturation curve, as well as the values for the armature reaction, can be pre-determined in normal machines with sufficient accuracy

to agree closely with figures obtained in test. How this is done has been described by various writers and need not be taken up on this occasion.

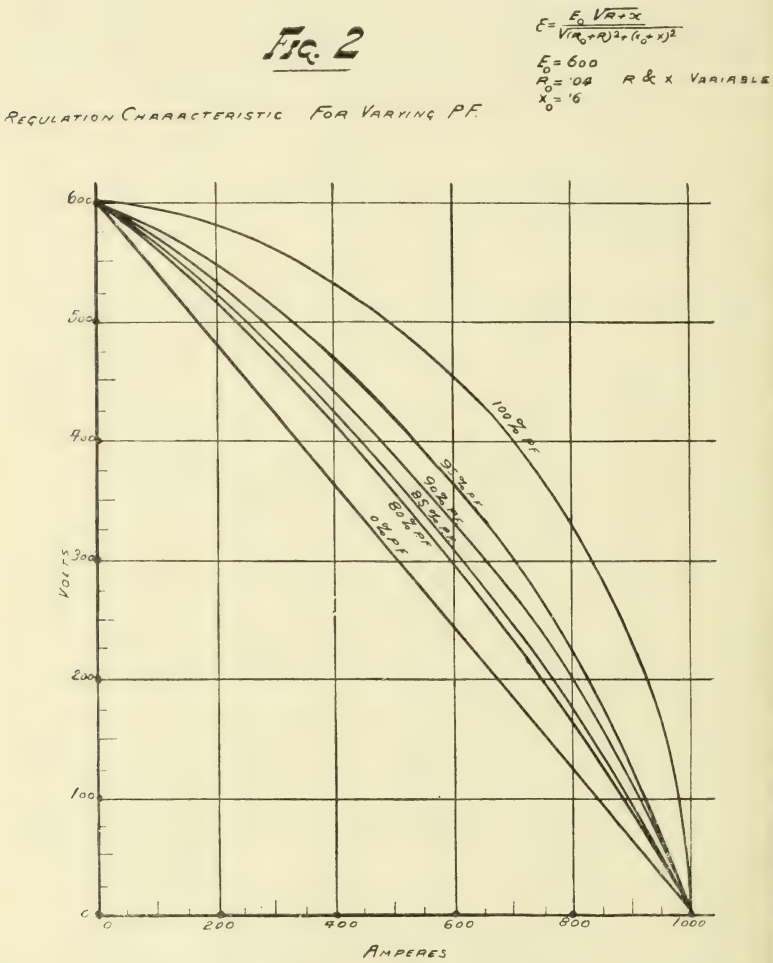


Fig. 2 is intended to illustrate the effect of a load of varying power factor on the regulation of a machine. Here the analytic method of Mr. Steinmetz has been used for calculating the different characteristics.* Although this method is not quite correct, as it assumes

* Steinmetz' Alternating Current Phenomena, 3rd edition, page 302.

constant saturation, it serves well to show what considerable influence a small deviation from unity power factor will have on the regulation, and how quickly the curves of lower power factor approach the straight line of zero power factor.

FIG 3

REGULATION CHARACTERISTIC FROM TEST

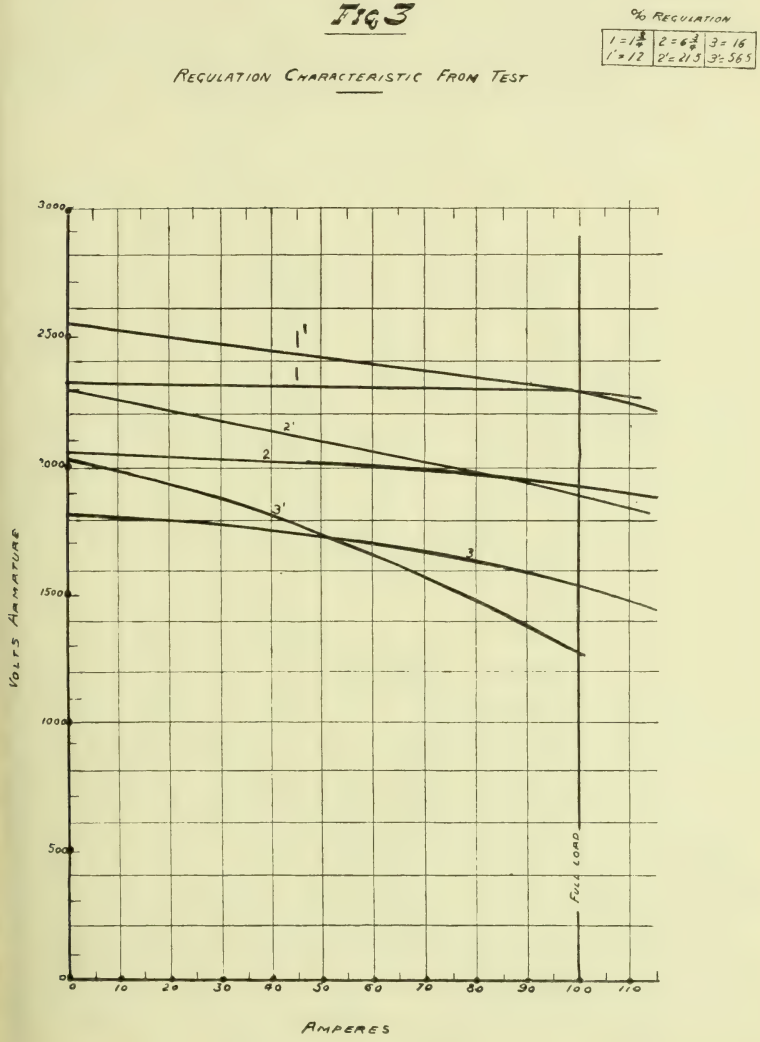


Fig. 3 shows test results which serve to further illustrate the points brought forth in Fig. 1. Three sets of curves are given, showing the

effect of gradually reducing in one case a non-inductive load and the other a highly inductive load. Curve 2 and curve 2^1 show this at normal voltage for non-inductive and inductive conditions respectively. Curves 1 and 1^1 show similar curves for a voltage approximately 20 per cent. above the normal, whilst 3 and 3^1 are intended for 20 per cent. below normal, but in the case of 3^1 it was not possible to obtain exactly the condition desired owing to the design of the synchronous motor used for obtaining the inductive load. Therefore this curve corresponds to a voltage of $32\frac{1}{2}$ per cent. below normal.

TABLE III.

% Reg. non-ind. load		% Reg. full and 80% P.f.		Ampt. field	% weight of field copper	% length of gap	Total ampt.—field	
Rise	Fall	Rise	Fall	ampt.arm.			% Gap	% Iron
2	2·5	8·0	17·5	6·87	218·1	243	95	5
4	5·0	12·5	22	4·28	136·1	118·2	89	11
6	8·0	15·0	35	3·15	100	100	83	15
7	11·5	17·0	44	2·72	86·5	85	85	17
8	13·0	18·0	50·5	2·47	78·6	75	82	18
10	19·0	20·0	66·5	2·07	65·8	60	78	22

In the above table a normal machine with a saturation curve as shown in Fig. 1 and with a regulation of 6 per cent. at full non-inductive load is taken as basis. The values for field copper and length of air-gap for this machine are taken as unity (100 per cent.), and corresponding figures for machines with a different regulation are given as per cent. of these. The table also serves to illustrate the relation between ampere turns field and ampere turns armature, and the division of the field ampere turns into the parts used for the air-gap and for the rest of the magnetic path. Finally, it gives also the different values when specifying the regulation as fall in voltage as referred to under heading 1. The considerable difference is due to the weaker field with no load excitation, which is more easily distorted by the armature reaction than the stronger one as given by the full load excitation.

As a further guide for specifying regulation figures, the following values can be recommended for different classes of service.

(a) Machines for lighting load or lighting load with incidental power work.

Sizes.	Regulation in per cent.		
	100 per cent.	95 per cent.	90 per cent. P.F.
Below 200 K.W.	5—7	9—11	11—13
Above 200 K.W.	4—5	7— 9	10—12

Under this class of service belong also generators driving rotary converters or synchronous motors.

(b) Machines for power work as given by induction motors.

	100 per cent.	95 per cent.	90 per cent.	85 per cent.	80 per cent.	75 per cent. P.F.
Below 200 K.W	7—8	11—13	13—15	15—17	16—18	18—20
Above 200 K.W.	6—7	10—12	12—14	14—16	15—17	17—19

Lower figures should only be chosen in exceptional cases, as they would mean an increase in cost not any more in proportion to the gain in regulation. On the other hand, in a number of cases—particularly in large "power" plants—somewhat higher figures than those given above are quite in order, and as they allow in all cases a further reduction in cost, they are well worth considering. To guard in case *b* against obtaining a machine in which regulation is obtained by undue saturation—thereby limiting the possibility of raising the voltage to compensate for any unexpected inductive drop in the feeders, it would be well to specify in addition to the above suggested figures, that the ratio of short-circuit current to full load current should not be less than $2\frac{1}{4}$—$2\frac{1}{2}$: 1 in machines below 200-K.W., and $2\frac{1}{2}$—3 : 1 in larger machines.

3.—Influence of Regulation on Efficiency and Operation.—

Not only the size and cost of alternating current generators are unfavourably influenced by too close a regulation, but the efficiency and the stability of operation are equally affected.

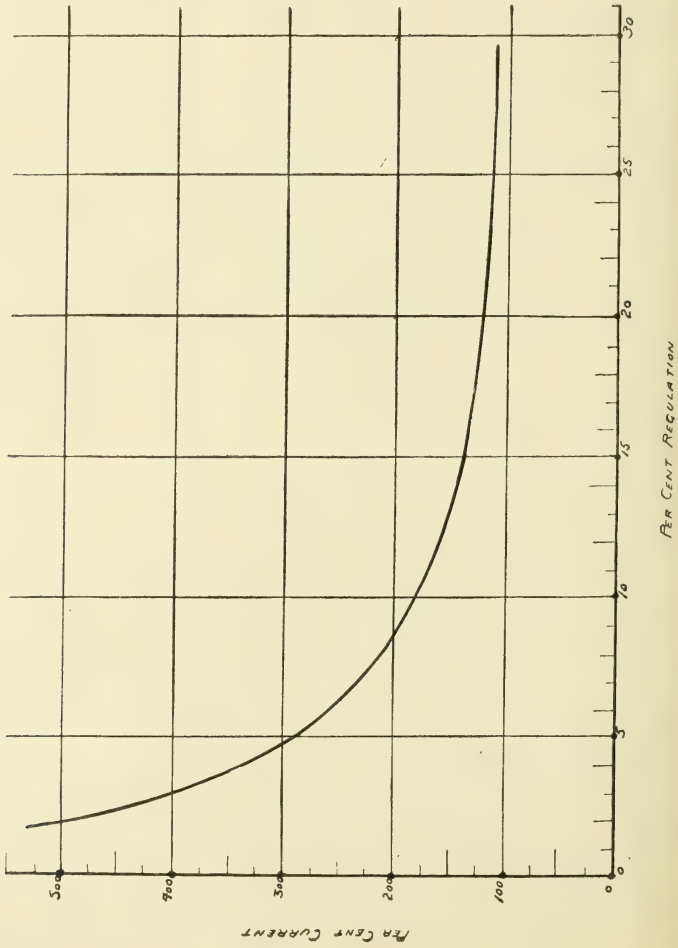
We have shown above that a smaller armature reaction requires a larger amount of iron to carry the magnetic flux, thus increasing the core-losses, which form the largest part of the losses in modern machines. Furthermore, the greater amount of field and armature copper will do their part towards a further decrease in the efficiency. Altogether, a reduction in efficiency from 1—$1\frac{1}{2}$ per cent. may be expected when changing a machine with an inherent regulation of say 7 per cent. into one with 4 per cent., without resorting to saturation.

In regard to stability of operation, it must be noted that very close regulating machines—due to their low armature reaction and self-

induction—will have a large short-circuiting current. In Fig. 4, the approximate relation between short-circuiting current and regulation is given for machines designed on the above principles (moderate saturation and C^2R loss armature assumed as 1 per cent.)

FIG. 4

RELATION BETWEEN % REGULATION FULL NON-INDUCTIVE-LOAD AND % SHORT-CIRCUIT CURRENT FOR MACHINE WITH MODERATE SATURATION AND ABOUT 1% C^2R LOSS IN ARMATURE



We therefore must expect with close regulating machines working in parallel, large cross currents and a considerable exchange of energy between the busbars and the generators if the cyclic irregularity inherent to all reciprocating engines is not kept to a very small amount by means of an extra large flywheel effect—which of course increases, unnecessarily, the cost of the plant. But even if all precautions are taken in this direction, troubles in parallel operation may readily occur with too close regulating machines due to the natural period of the alternator becoming such as to introduce the danger of resonance with the forced oscillations of the engine. The following simple formula for the free oscillation of an alternator further explains this point. *

Time of oscillation—

$$= \text{Const.} \sqrt{\text{moment of inertia} \times \text{self-induction of machine}},$$

or expressed in words, this means that for a given moment of inertia the natural frequency of an alternator is inversely proportional to the square root out of the self-induction of the machine. For safe parallel operation it is desirable to have this period as low as possible, so as to keep away from the period of forced oscillation as given chiefly by $\frac{r.\ p.\ m.}{60} \times 1$ and $\frac{r.\ p.\ m.}{60} \times 2$ the number of steam impulses per revolution. Therefore the self-induction of the alternator should be large, which, however, as shown above, is opposed to close regulation.

Large currents on short circuit also tend to cause troubles in plants as required for rolling mills and mining work, where, due to the rough service—heavy overloads and even short circuits may frequently occur. Here the maximum generator current, as caused by a complete short circuit, should always be limited to about $2\frac{1}{4}$ to $2\frac{1}{2}$ times its normal value.

4.—*Regulation for Constant Power or Current.*—

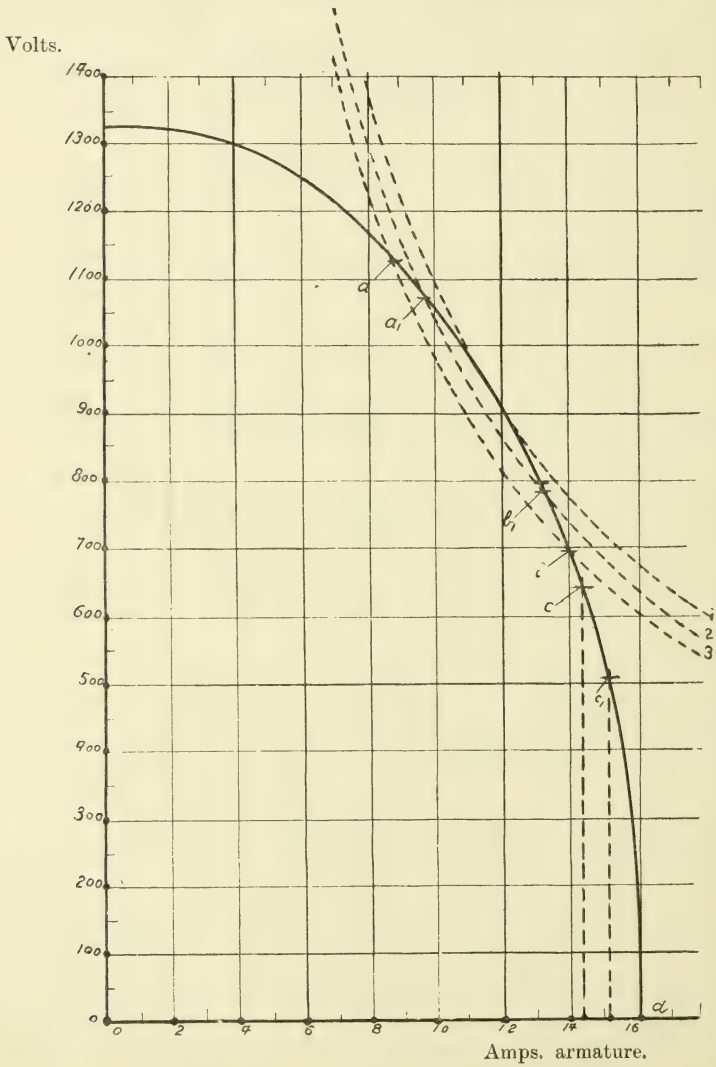
While within the above discussed limits a close regulation should be aimed at in all normal machines, there are also cases where a poor regulation is essential. This refers to alternating current generators for constant power or constant current work as required for certain electrolytic processes, such as the manufacture of calcium, carbide or carborundum, where the current is used for feeding an arc. The nature of the work requires here approximately constant current for large variations in the resistance of the arc, as caused by the feeding of new material into the furnace, or by a change in the resistance of the material itself, such as carbon. In this case the best working conditions are obtained by designing the alternators with so large an

* See Görges E.T.Z., 8th March, 1900, page 19.

armature reaction that, with increased armature current, the field and consequently the voltage is so much weakened that either the product of volts times amperes remains constant, or the current itself remains

FIG 5

REGULATION CHARACTERISTIC FOR CONSTANT POWER AND CONSTANT CURRENT.



constant, over a wide range of the characteristic. A short air gap will add to make the armature re-action more effective.

In Fig. 5 the characteristic of such a generator is shown by the full drawn curve. The dotted curves represent lines of equal power, and are drawn so that No. 1 represents the maximum output of the machine, No. 2 is 5 per cent. less, and No. 3 10 per cent. less than No. 1: thus between the points a and c, that is, between 700 and 1130 volts, the power of the generator does not vary more than 10 per cent., and between a and b, *i.e.*, between 790 and 1075 volts not more than 5 per cent. In the same manner the dotted lines from c and c^1 show that part of the characteristics—where the current keeps approximately constant, *i.e.*, between 0 and 510 volts, the current does not vary more than 5 per cent., and between 0-645 volts not more than 10 per cent.

5.—*Regulation on Unbalanced Circuits.*—

The preceding discussion of inherent regulation applies to balanced circuits only. If the current or the phase relation between the current and E.M.F. becomes different in the different branches of a polyphase generator, the terminal voltages also become different, since, due to the common excitation, the E.M.F. induced in each phase is the same while the drop, of course, is different. In 2-phase machines where the phases are kept separate, the voltage of the unloaded phase will also drop to some extent when loading the other phase, and therefore in all cases the difference between the E.M.F. of the loaded and unloaded phase is here less than the inherent regulation of the machine. Much more complicated is the matter in 3-phase machines, where the phases are interconnected. Here it is almost impossible to predict the resulting conditions to any degree of accuracy, since the current, even if it is in phase with the terminal E.M.F., will necessarily be lagging in regard to one phase of the winding, and leading in regard to the other, and consequently its effect on the voltage of these phases will be such as to cause a drop in the first, and a rise in the second case. Furthermore, the higher harmonics, especially the third, introduced by unbalancing, will superimpose effects which are almost impossible to predetermine. A more detailed consideration of this question falls outside the scope of this paper.

(B) INFLUENCE OF VOLTAGE REGULATION ON THE SYSTEM.

While above the question of voltage regulation has been dealt with as far as the generators are concerned, we now have to consider the effect which such changes in voltage as caused by the inherent regulation will have on the system.

1.—*Incandescent Lighting.*—

The supply of incandescent lamps demands an almost perfect regulation, since changes—even if only of the order of two to three per cent.—will have serious consequences for the life and efficiency of the lamps, and therefore it is evident that all ordinary generators, when left to themselves, cannot satisfactorily supply a lighting system. In all cases careful attendance at the switchboard is required, which follows any change in load, with a corresponding change in excitation. In larger stations, this method meets all the requirements of a first-class illumination, but in smaller plants with perhaps only one generator, a noticeable flicker in the lamps can hardly be avoided every time the load is suddenly increased or decreased to any extent. These conditions are considerably aggravated as soon as motors are on the system, and it is this point which has forcibly brought before the engineers the question of automatic voltage regulation. However, before discussing the suggested remedies, we ought to be fully acquainted with the cause of the troubles and therefore have to further investigate the mutual influence of the generator regulation on the performance of the motors, and vice versa.

2.—*Induction Motors.*—

It is well known that this type of alternating current motor will always take a lagging current from the system, and therefore its power factor must be below unity. The actual value will depend on two factors in the design of the machines, viz. :—on the necessary magneto-motive force to produce the working flux, and the primary and secondary leakage. While the former is independent of the load, but varies directly as the impressed voltage, the latter is independent of the voltage but proportional to the load. Therefore, a reduction in voltage will somewhat improve the power factor at light loads, where the leakage has little influence, but, on the other hand, the output and torque of an induction motor which vary as the square of the voltage, will be reduced to a much larger extent, and thereby the working of the motor on overloads will be endangered. It is this point which makes the voltage regulation so important for the determination of the right size of motor, particularly in cases where the service demands at intervals the maximum output or maximum torque from the machines.

To return to the question of power factor: Under full load and at standard speed, this should lie with a well-designed polyphase

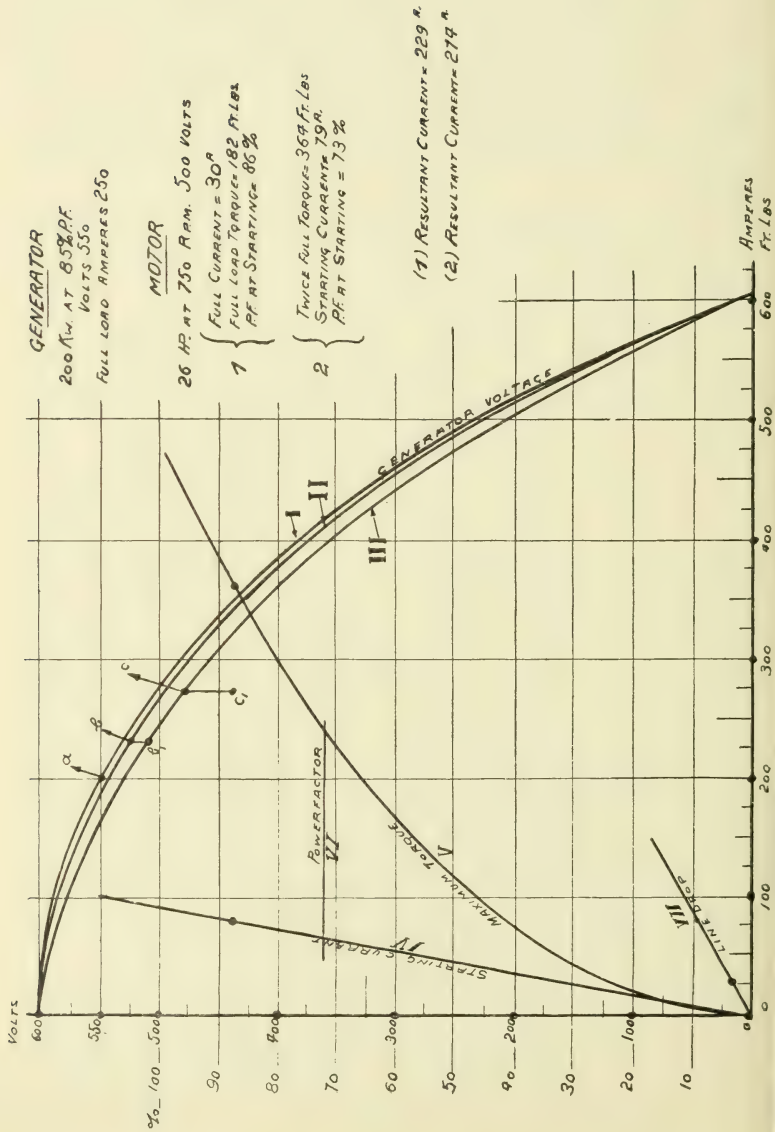
induction motor, between 90 and 95 per cent. (the latter figure for 25 cycle machines), but when running partially loaded or with slow speed motors or single phase machines, figures much below those mentioned must be expected, and since on a system of motors hardly ever all of them will run under the most favourable conditions for the power factor, we can assume that where motors are used on a supply system, they will introduce lagging currents amounting to about 60 per cent. of the rated load current of the motor load. By combining separately the wattless and the energy current thus introduced with the corresponding currents of the rest of the load, the resultant power factor will be obtained on which the regulation of the generator depends.

Of special interest for the point under discussion, is the starting performance of this class of machines. We have here to differentiate between squirrel cage and slip ring motors.

The first-named type will start in smaller sizes with one and a half to twice its normal rated torque, taking about four to five times its rated full load current. In larger sizes, the starting torque will lie between full load and one and a half times full load torque—the starting current between five and seven times full load current. The power factor at starting depends a good deal upon the design, but it is not as low as commonly assumed; for instance, in the smaller motors, values between 60 per cent. to 75 per cent.; in the larger motors between 40 per cent. to 60 per cent. can be expected. But even such figures as given above, limit in ordinary systems the size of squirrel cage motors which should be allowed to start under full voltage to a small fraction of the generator output. On the other hand, in cases where only a starting torque, say up to half full load torque is required, the conditions can be considerably improved by starting devices which reduce during starting the voltage at the motor terminals in such a manner that the current on the line side is reduced in the same proportion as the torque, *i.e.*, as the square of the reduction in the voltage. In such cases, squirrel cage induction motors, which in regard to simplicity, reliability and efficiency cannot be equalled, may be installed also in larger sizes without interfering with the voltage regulation to an objectionable extent.

The second type, which uses resistance in the secondary, can be started with full load torque and full load current, or with a larger torque up to a maximum of about three times normal, taking correspondingly more starting current. The power factor at starting is dependent on the starting current, and will lie between 80 to 90 per

Fig. 6


GENERATOR
200 Kw. AT 85% P.F.
VOLTS 550
FULL LOAD AMPERES 250
MOTOR
26 HP. AT 750 R.P.M. 500 VOLTS
1 FULL CURRENT = 30A
FULL LOAD TORQUE = 182 FT. LBS.
P.F. AT STARTING = 86%
2 TWICE FULL TORQUE = 364 FT. LBS
STARTING CURRENT = 79A.
P.F. AT STARTING = 73%
(1) RESULTANT CURRENT = 229 A.
(2) RESULTANT CURRENT = 274 A.
GENERATOR VOLTAGE
MAXIMUM TORQUE
STARTING CURRENT
POWER FACTOR
LINE DROP
I
II
III
IV
V
VI
VII
VOLTS
%
AMPERES
FT. LBS

cent. when starting with full load to twice full load torque, and somewhat lower when starting under still heavier load.

To illustrate the influence that a comparatively large induction motor starting under heavy load will have on the generator regulation, and also the influence of the voltage regulation on the torque of such motors, Fig. 6 has been prepared. Here we have assumed a generator rated to give 200 K.W. at 85 per cent. power factor. The normal voltage to be 550, and the regulation on full non-inductive load to be 6 per cent. Fig. 1 to represent again the saturation curve of this machine. It is further assumed that the generator at a given moment is running under a mixed power and lighting load of 200 amperes at 95 per cent. power factor, the voltage for this load (point *a*) being adjusted to 550. Curve I shows the regulation characteristic at 95 per cent. power factor. Under these conditions, a 26 H.P. polyphase induction is started first under full load torque, second under twice full load torque.

The induction motor of the slip ring type to be designed for intermittent service, and a synchronous speed of 750 r.p.m. With the proper resistance inserted in its secondary, it will start with 182 foot pounds torque, taking about 30 amperes—the value of full load current of the motor—at 86 per cent. power factor. The effect of starting a motor under these conditions will be to load the generator with a resultant current of 229 amperes at 94 per cent. power factor. By referring to curve II, which shows the characteristic at this power factor, we find that the corresponding generator voltage will now be 525 volts (*b*). It is further assumed that the line drop between busbars and induction motor at 30 amperes is 3 per cent., so that the available voltage at the terminals of the motor is 510 volts, or above the rated voltage.

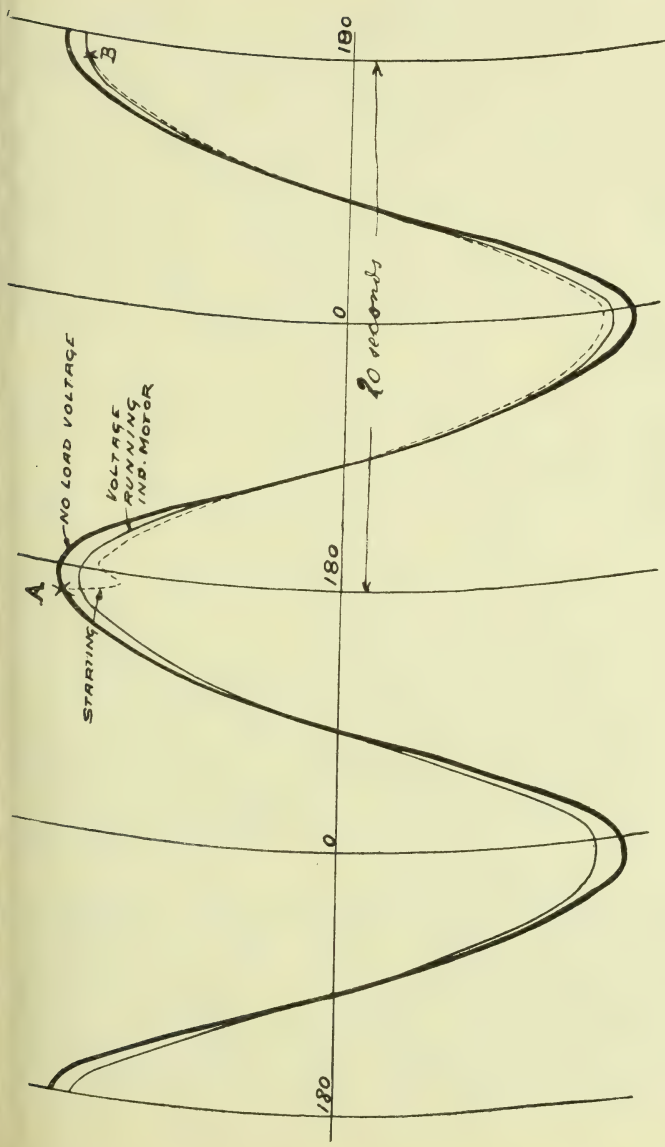
In the second case, the motor has to start under twice its normal torque, or 364-foot pounds. To find whether the motor will be able to comply with these requirements, its maximum torque has been plotted in curve V, whilst curve IV shows the starting current, and curve VI the power factor when starting under these conditions. It will be seen that to exert a torque of 364-foot pounds 435 volts are required, which gives 79 amperes at 73 per cent. power factor. By combining the corresponding currents, a resultant power factor of 90 per cent. is obtained, for which the regulation characteristic has been plotted in curve III. To simplify matters, the line drop has been taken as a straight line, *i.e.*, depending on the ohmic drop only, though probably in a great number of cases overhead conductors are

used, and in that case, the inductive drop for such large currents may be considerable, and should be carefully figured. Point (*c*) 480 volts gives for this case the generator voltage, and after subtracting the line drop of 8 per cent. a voltage of 435 remains available at the motor terminals, or just sufficient to give the required torque as a maximum possible torque. In practice, of course, such extreme cases as the one described could be readily met by either a modification in the design of the plant, or by a signal system between the motor and the power station, which allows to always notify the station before starting the motor under its maximum load.

While the above Fig. 6 was drawn for the specific purpose described, it also serves to show that it is wrong and unfair to restrict the starting current of an induction motor to a certain per cent. of its full load current, as this is done by a great number of supply stations in this country. Such restriction permits a 10 H.P. motor in the same way as a 1 H.P. motor, though the disturbance in the voltage regulation in the former case would be ten times as large. Furthermore, it gives the advantage to the poorer motor, as this will have a larger full load current, due to the lower apparent efficiency. The correct way is to either place a limit on the amount of current, which may be taken at starting, or still better, vary the restrictions for each size and grade of motor.

In Fig. 7 a further illustration of the above discussed interference between the generator regulation and the starting of a large induction motor is given. The curves represented were obtained from an ondograph as described in detail by M. Hospitalier before the Inst. of Electrical Engineers on 10th December, 1903. This interesting apparatus registers the momentary values of the E.M.F. by a condenser discharge into a galvanometer. This discharge takes place 999 times for 1,000 cycles of the machine under observation. In the case given, *i.e.*, for a frequency of 50 cycles per second, it takes 20 seconds to plot one complete cycle of the E.M.F. wave. The heavy lined curve in Fig. 7 shows the no-load voltage of a 100 K.W. three-phase generator. While the needle was registering a second time, point *a*, a 30 H.P. induction motor starting against full load torque was switched on. The dotted line shows the effect on the generator voltage, *i.e.*, it causes a momentary drop of about 20 per cent., part of which is undoubtedly due to the momentum of the needle, which explains also the following sharp upward movement. Altogether, it took about 19 seconds until the final running voltage which lays about 7 per cent. below the no-load voltage was reached in point B—which

Fig. 7



EFFECT OF STARTING 30 HP INDUCTION MOTOR ON VOLTAGE CURVE OF 100 KW GENERATOR TAKEN BY HOSPITALIER'S ONDOGRAPH

was found when the needle passed a second time through B, registering now the thinner full drawn curve. The time of disturbance agreed well with the time it took the motor to get up to speed.

3.—*Synchronous Motors.*—

While the power factor of an induction motor—as seen in the preceding—is fixed by the design, and its current is always lagging, that of the synchronous motor can be made leading or lagging at will by varying the strength of the field excitation. Hence, this type of motor offers a simple method of compensating for the effects of inductive loads in other parts of a power system. For instance, if the same amount of power is furnished by synchronous and asynchronous machinery, and the leading currents produced by the former are made equal to the lagging currents taken by the latter, the resultant power factor of the system will be unity, and therefore, the effect on the generator regulation a minimum, and the efficiency of transmission a maximum.

The amount of over-excitation necessary to compensate for a certain lagging current, can be readily pre-determined.* It might roughly be stated that if a synchronous motor is over-excited so as to take a resultant current 5, 10 or 15 per cent. greater than its normal load current, it is capable of compensating for a lagging current 32, 46, 57 per cent. as great as its normal load current.

The most efficient way of using such machines as "rotary condensers," is by loading same with 71 per cent. of their rated output mechanically, and then raising the excitation until the resultant current is equal to the rated current. We thus obtain a leading component $= \sqrt{1{\cdot}00^2 - {\cdot}71^2} = 71$ per cent. *i.e.*, of the same magnitude as the energy component. The principle set forth above is used in America in a number of practical cases—for instance, in the transmission system Montreal—Chambly, and in Butte Montana and other places.

The following may serve as a general example of the results obtainable by this method.

Assuming a mixed power and lighting plant having an average day load of 350-K.W. consisting of induction motors and transformers supplying the lighting net-work. Since the latter during the day are only very lightly loaded, the resultant power factor will probably be not more than 70 per cent.—which means the apparent station output is 500-K.V.A. plus the the losses in the transmission. Now, if instead

* See E. J. Berg, "Electrical World," 13th January, 1900.

of using induction motors throughout, part of the power, say 100 K.W. had been installed as synchronous motors, these being so designed as to allow by proper over-excitation a continuous output of 141 K.V.A.—the conditions would be changed to those represented graphically in

FIG. 8.

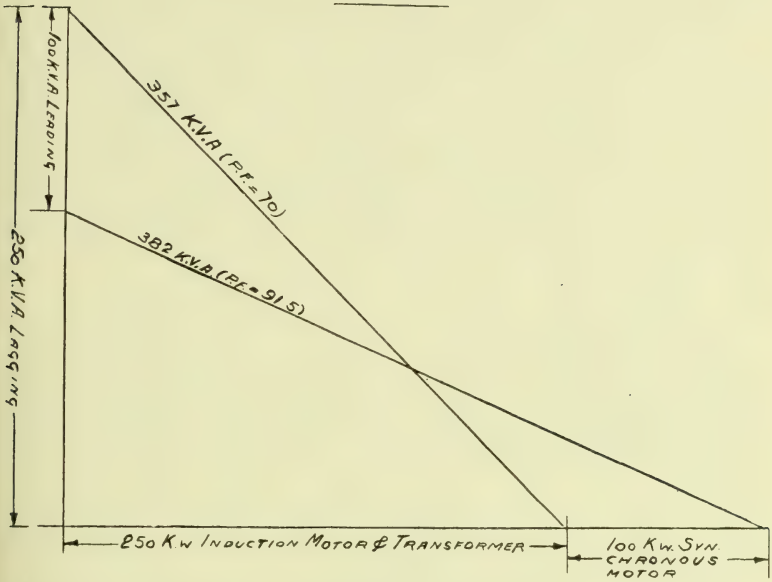


Fig. 8. One now has to combine 250-K.W. at a lagging power factor of 70 per cent. with 100-K.W. at a leading power factor of 71 per cent. This gives 350-K.W. at a resultant power factor of 91·5 per cent. or 382 K.V.A. as against 500-K.V.A. in the first case. This is a clear saving of 118 K.V.A., or 24 per cent. effected by the judicious installation of synchronous machinery.

In spite of such considerable advantages as may be obtained by controlling the power factor, a more general introduction of this class of alternating current motors for power work is greatly hampered by their inferiority in regard to starting torque. They can be built to start light or even with a small load, but in doing so draw a large lagging current from the line with the same detrimental effect to the generator regulation as referred to under the heading of squirrel cage induction motors. To improve matters they also require a reduced voltage at starting, but as the starting torque per ampere starting

current is considerably less in a synchronous motor than in an induction motor, the results obtainable are less favourable and limit the usefulness of the former class to cases where only a small starting torque and unfrequent starting is required.

But even if all these conditions are fulfilled, it must not be overlooked that too many synchronous motors on one system may also lead to trouble, as they are extremely sensitive to any fluctuations in the voltage or impressed frequency, as may be caused by the prime movers. For instance, in the Niagara Power Transmission, this trouble became very noticeable, and only ceased after installing some large induction motors, which acted as electrical dash-pots against surging. Another point which must be considered wherever synchronous motors are used, is the possibility of abnormal rise in voltage, due to resonance effect either at the fundamental frequency or at those corresponding to higher harmonics.

(C) AUTOMATIC VOLTAGE REGULATION AND COMPOUNDING.

To complete the discussion on voltage regulation in alternating current systems, the third part of these notes will be devoted to a general review of the methods used for keeping the supply voltage automatically constant with varying loads. However, in view of the limits set to the length of this paper, it is impossible to describe in detail all the ingenious inventions which have been brought out to serve this purpose. We have to limit ourselves to a description of the general arrangements of the most important ones, giving working results only of one type with which the author had personal experience of a very encouraging nature.

According to their action, the methods commercially introduced for compounding alternating current generators may be divided into four classes :—

(1) Mechanical influence on the exciter rheostat.

(2) Use of a pulsating excitation in the exciter field.

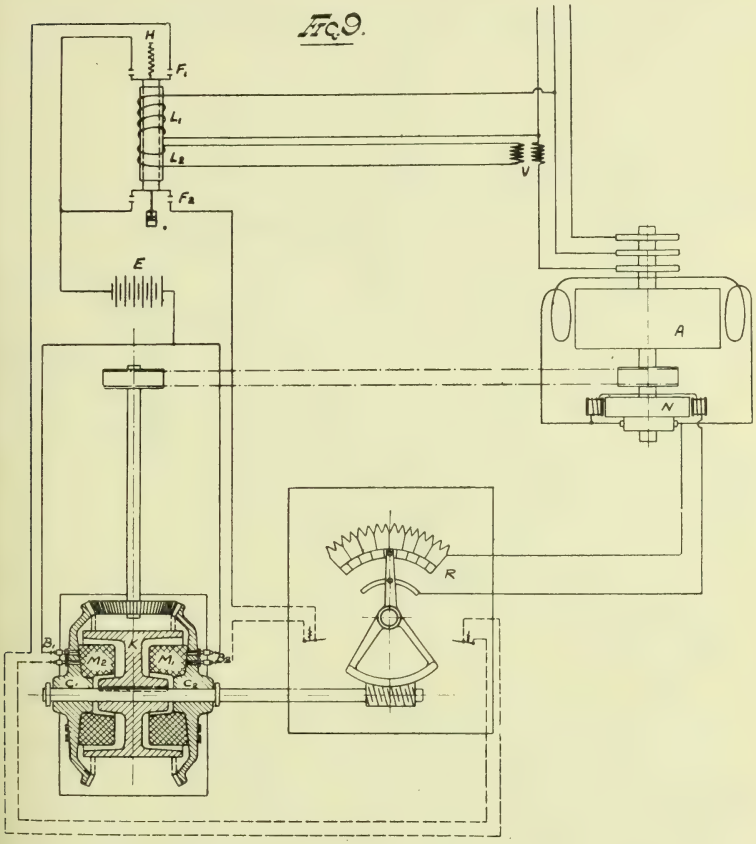
(3) Influence on the armature reaction of the exciter.

(4) Self-excitation by means of rectified or low periodicity alternating currents.

1.—*Mechanical influence on the exciter rheostat.*—

Fig. 9 gives a general illustration of this method. A represents the alternator, N the exciter, R is the rheostat in the exciter field. Its handle is worked by means of a worm gearing from a magnetic clutch K, which is controlled by the relay L. The latter device is shown as

a solenoid acting against a spring. In accordance with a lower or higher supply voltage, either the spring or the solenoid will be more powerful, thereby closing the energizing circuit of M^1 respectively M^2, thus increasing or reducing the resistance R. By adding a second coil L^2 wound in opposition to L^1 and controlled from the secondary of a current transformer V, the primary of which is in series with one

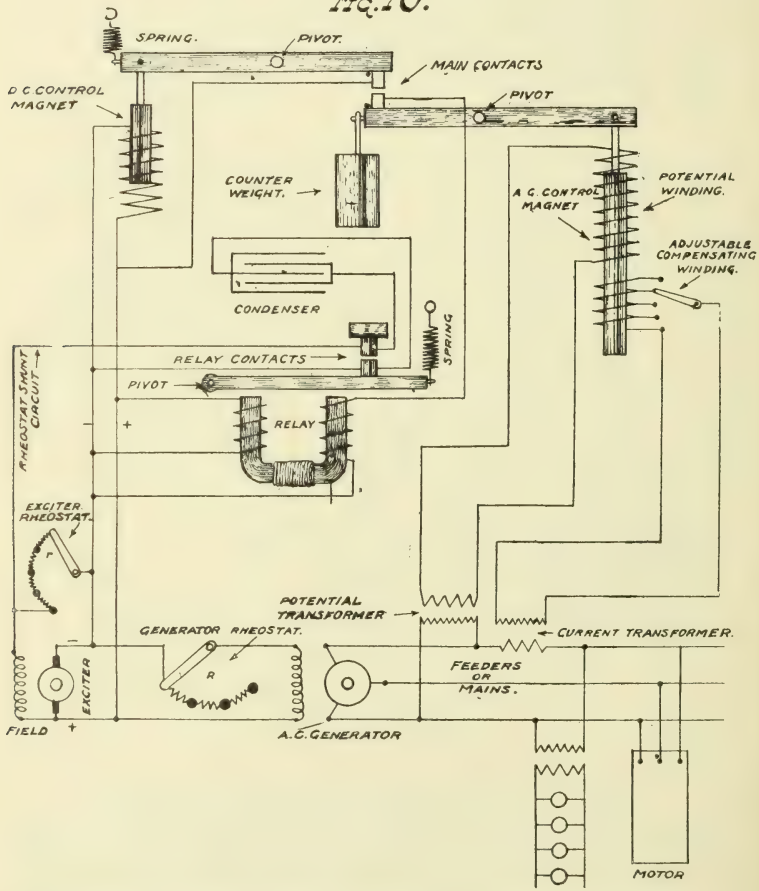


of the main lines, over-compounding with increasing current can be obtained. The above scheme has been successfully used in a number of plants, where the nature of the load introduces only very gradual changes in load. For all other purposes it cannot be recommended, since the time lag between action and reaction is too large to allow a satisfactory regulation of the voltage.

2.—*Use of a pulsating excitation in the exciter field.*—

Somewhat similar in its general arrangement, but radically different in its working principle, is the device we have now to consider, and which has been invented by A. A. Tirril, of the General Electric Co. of America. The main distinguishing feature of this regulator is the control of voltage by rapidly opening and closing a shunt circuit across the exciter field rheostat, thus giving the exciting current of the exciter a more or less pulsating character. The frequency of the make and break of this circuit is controlled by the voltage, and, if desired, also

FIG. 10.



ELEMENTARY CONNECTIONS OF TYPE TO FORM A VOLTAGE REGULATOR FOR GENERATORS.

by the current of the generator, and varies from about 1 to 20 per second. The smallest drop from the desired voltage will cause the rheostat to remain short-circuiting for a longer period, thereby raising at once the voltage of the exciter and of the main generator. To avoid sparking at the contacts, a condenser is shunted across the breaking points. Fig. 10 gives the diagram of connections of the regulator as actually built.

The rheostat shunt circuit is opened and closed by a differentially wound relay. The current for operating this relay is taken from the exciter bus-bars, and is controlled by the floating main contacts. The current for operating the direct current control magnet is also taken from the exciter bus-bars. The relay and the direct current control magnet constitute the direct current portion of the regulator, and maintain not a constant but a steady exciter voltage. The alternating current portion of the regulator consists of a magnet having a potential winding connected, by means of a potential transformer, to the bus-bars or the circuit to be regulated. This magnet also has an adjustable compensating winding which is connected in series with the secondary of a current transformer usually inserted in the principal lighting circuit. The core of this magnet is attached to a pivoted lever carrying a counterweight which is balanced by the attractions of the magnet. If a load is thrown on the generator the voltage will tend to drop, the alternating magnet current will weaken and destroy the balance of the core and lever and cause the main contacts to close; this, in turn, will close the relay contacts and entirely short-circuit the exciter field rhesotat, thus increasing the exciter voltage until the original balance of the alternating current magnet core and lever is restored and the alternating current voltage maintained at the required value.

In some cases, the exciter voltage will vary from 70 to 125 volts from no load to full load. This is especially true if the load is partly inductive and the regulator is adjusted to compensate for the line loss. In order to get the full range of regulation within the scope of the regulator in such cases, the alternating field rheostat should be turned entirely out and the exciter field rheostat adjusted to lower the alternating current voltage about 65 per cent. below normal. When the regulator is switched in it will close the rheostat shunt circuit and instantly build the voltage up to normal.

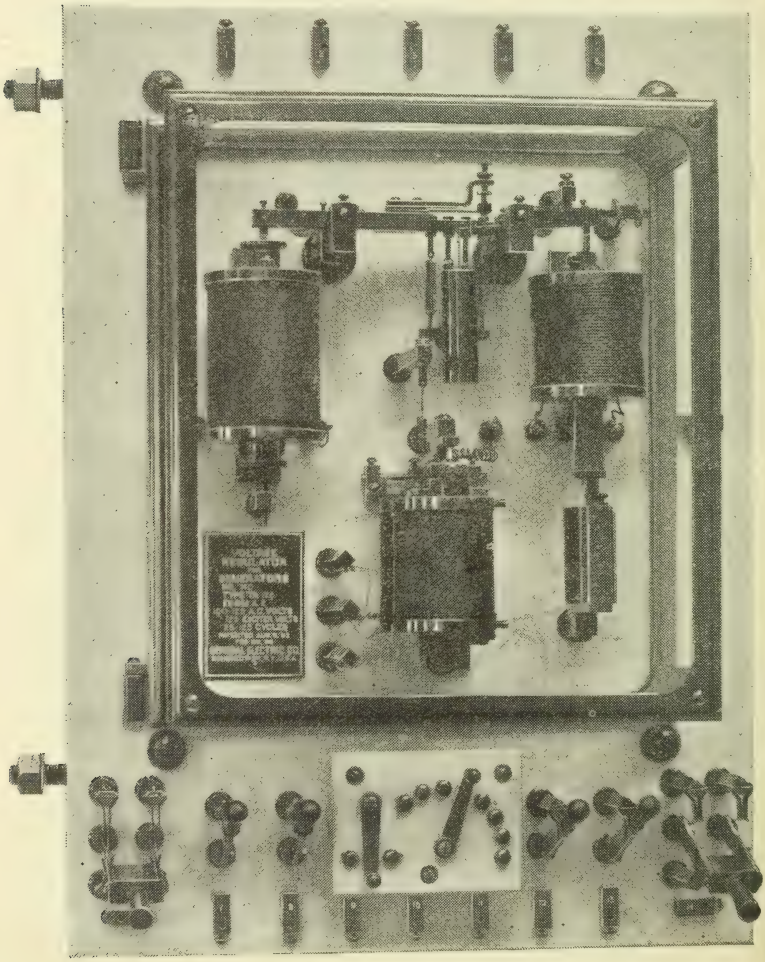
Once the regulator is adjusted to maintain a desired voltage, it will maintain it under all ordinary conditions of load or speed without further adjustment, and since the moving parts of this regulator are

very light and move only a short distance (about $\frac{1}{16}$th) they can act instantly without any chance of hunting.

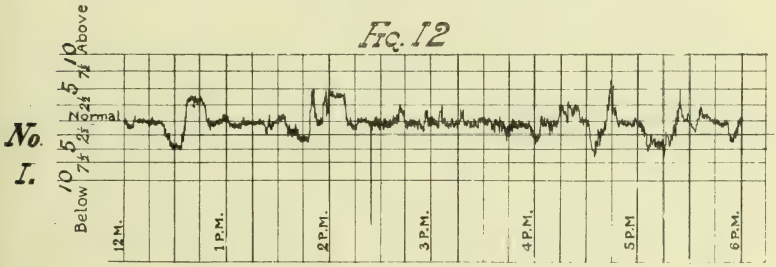
The regulator may be put in and out of service at any time, without interfering with the voltage, and any number of alternators can be run in parallel—using the same regulator—provided the exciters are also run in parallel. If the generators are in parallel and the exciters are not, it would require a regulator for each of the exciters, which have to run at the same time.

In Fig. 11 the outside appearance of the device is shown. The

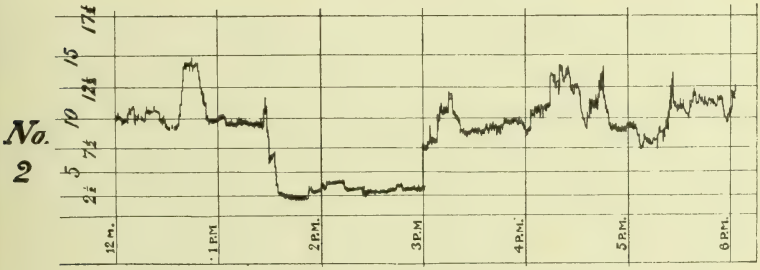
Fig. 11.



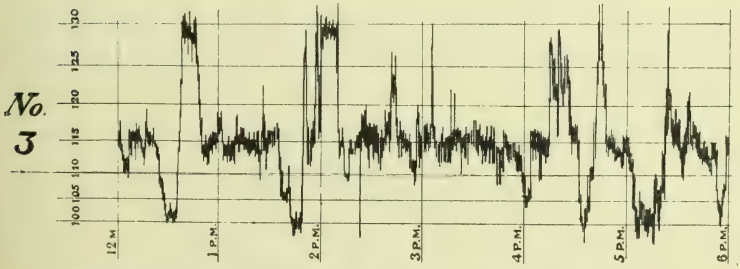
base on which it is mounted is 15 inches by $20\frac{1}{2}$ inches, and therefore the complete apparatus can also be placed on a standard switchboard panel. The capacity of the plant which is to be regulated only affects the condenser capacity, which must be shunted across the contact points. Thus it has been found that for every 15 K.W. of exciter capacity corresponding to about 1,000 K.W. generator capacity, one condenser section of about $2\frac{1}{2}$ microfarad is required.



Recorded Speed Normal 900 R.P.M.
Per cent. variation from normal speed. Without Voltage Regulator.

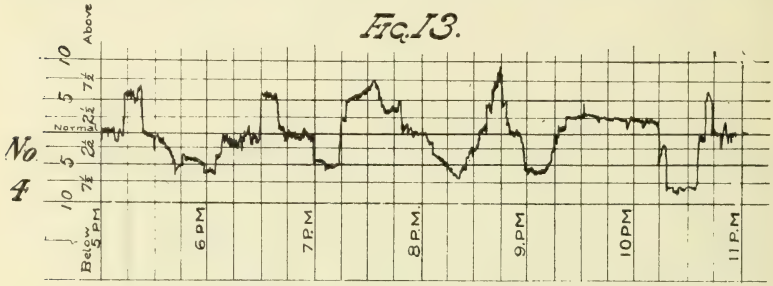


Amperes on Primary, at 2,000 to 2,600 Volts.
Without Voltage Regulator.

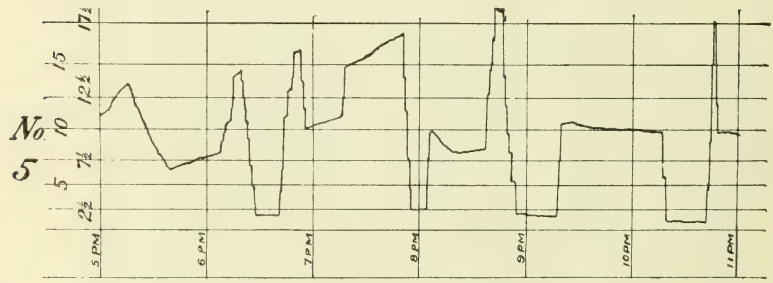


Recorded Secondary Volts Transformer. Ratio 20 : 1.
Without Voltage Regulator.

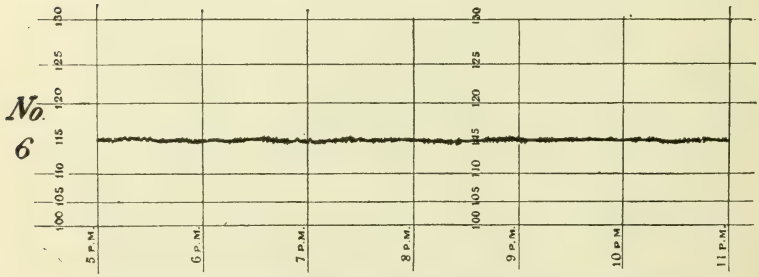
In Figs. 12 and 13, some charts are given, illustrating the working of this device on a standard 75 K.W. generator with direct connected exciter and a normal speed of 900 r.p.m. The generator was driven by a shunt motor, and the normal variations of speed shown in Chart 1, were due to changes of load on the generator and changes of voltage on the motor supply circuit. The 5 per cent. speed



Recorded Speed Normal 900 R.P.M.
Per cent. variation from normal speed. With Voltage Regulator.



Amperes on Primary, at 2,300 Volts.
With Voltage Regulator.



Recorded Secondary Volts Transformer. Ratio 20 : 1.
With Voltage Regulator.

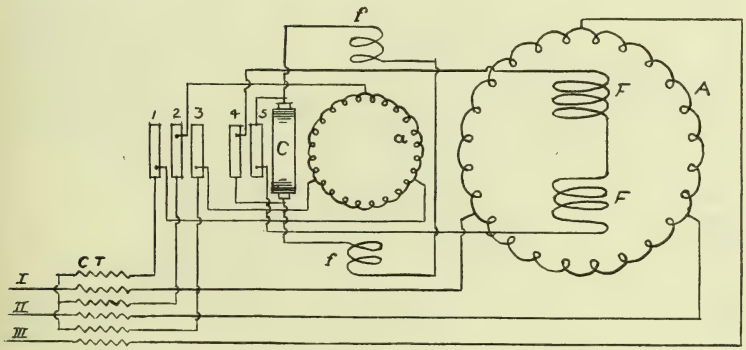
changes were made purposely to show the effect on the voltage. The motor was allowed to run with practically no attempt to regulate its speed.

The second chart gives the load in amperes on the generator, showing at times about three-quarters full load.

The third chart shows the voltage which was not regulated after once set at 115 volts. This chart shows that with a direct connected exciter a speed change of 8 per cent. may cause a variation of about 32 per cent. in the voltage of the alternator, giving a ratio of about 4·1.

The next set of charts, 4, 5 and 6, were taken on the same generator, under more severe conditions, but using the regulator to maintain constant voltage. Chart 4 shows that the speed changes were greater with the regulator than without, as on chart 1 the extreme speed variation was only about 10 per cent., while on chart 4 the speed change was about 20 per cent. A load having various power factors was frequently changed, as may be seen on chart 5, and, notwith-

FIG. 14.



A = ARM. WINDING } GENERATOR
F = REV FIELD
a = ARM WINDING } EXCITER
f = FIELD "
C = COMMUTATOR
1.2.3. = SLIPRINGS FOR A.C
4.5. = SLIPRINGS FOR D.C.
CT = CURRENT TRANSFORMER

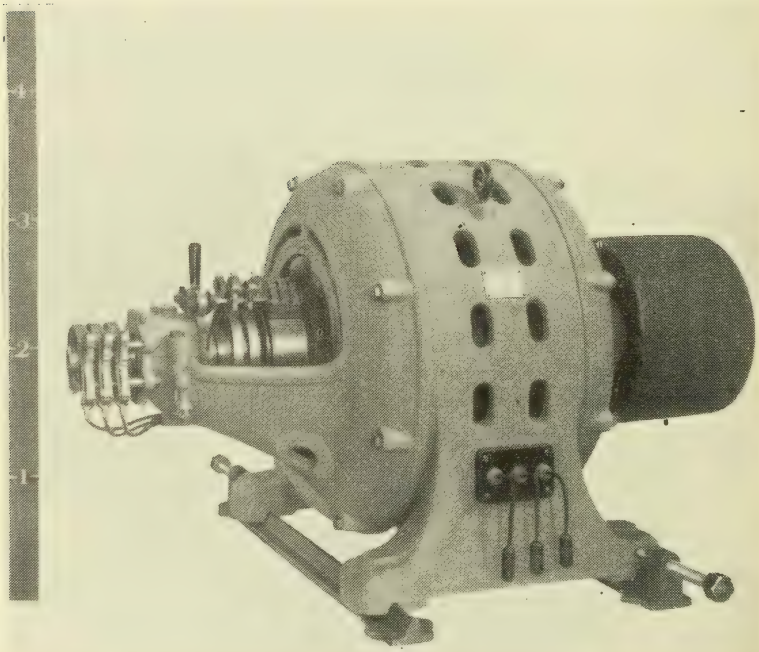
standing these severe conditions, the regulator maintained a voltage within one-half volt, as will be seen by the practically perfect chart 6.

It may be added that more than 100 of these regulators have been installed in the States within the last 18 months.

3.—*Influence on the armature reaction of the exciter.*—

Here we have to mention in the first place the compensated generator as developed by the General Electric Co. of America, of which about 30,000-K.W. are in successful use in the States in sizes

Fig. 15.



100 K.W. 900 R.P.M. 60 Cycles—2,300 Volts..

from 50 to 500-K.W. The general arrangement is illustrated by Fig. 14, the outside appearance of the complete machine in Fig. 15. The main point is to obtain a current in the exciter armature of the same periodicity as the generator current; therefore the exciter which is

built into the generator frame has to have the same number of poles as the generator, except where gearing instead of direct connection is chosen. By means of the series transformer CT and the collector rings 1, 2, 3, the generator current is made to re-act magnetically on the exciter field in proportion to the strength and phase relation of this current. Consequently the resultant magnetic field and hence the voltage of the exciter is due to the combined effect of the shunt field current and the magnetization of the alternating current flowing in the armature. This automatically gives the necessary rise in the exciter voltage for all loads, non-inductive and inductive. To be able to vary the degree of compounding, the position of the exciter field in respect to the armature winding of the alternator can be altered by turning the field structure of the exciter through a certain angle. The exciter must work on the straight part of the saturation curve, so as to obtain the voltage proportional to the ampere turns.

The special nature of the exciter limits this type of generator to sizes mentioned above and to machines of a moderate number of poles.

Before leaving the subject of compounding by means of specially arranged exciters, one ought to mention the scheme devised by M. Leblanc, the working of which was demonstrated at the Paris Exhibition. However, the complications inherent to this arrangement have apparently prevented its commercial introduction, and therefore a further description falls outside the scope of this paper.

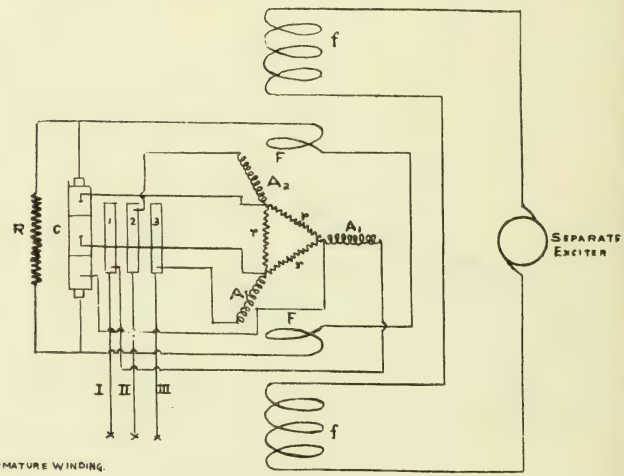
4.—*Compounding by means of rectified or low periodicity alternating currents.*—

The earliest and the latest attempt to solve the question of automatic compounding with the load fall under this heading. The General Electric Co. and the Westinghouse Co. in America, further, Ganz & Co. on the Continent, have built since the early days of our art, alternators which were provided with a commutator and a series winding on the field in a similar manner as compound wound direct current generators. Fig. 16 shows the arrangement as used by the first-named firm. A three-part commutator each with as many segments as there are pairs of poles rectifies the current from the three phases. The rotating shunt reserves as neutral point for the winding, and at the same time prevents its being opened in case of a break in contact at the commutator. The stationary shunt R. is adjustable so as to be able to vary the compounding for loads with different power factors. Both shunts also serve to reduce the sparking at the commutator.

These machines were built with a separate shunt excitation, so as to keep the commutator as small as possible. By the introduction of revolving field machines, and the more advanced schemes of compounding as described under (2) and (3), this type of machine has been superseded.

Quite recently some new arrangements have been brought out by M. Latour and by A. Heyland, which both revive the idea of using a

FIG. 16.



$A_1 A_2 A_3$. 3 PHASE ARMATURE WINDING.
r ROTATING SHUNT.
R STATIONARY SHUNT.
C RECTIFYING COMMUTATOR
F SERIES FIELD WINDING
f SEPARATELY EXCITED WINDING

commutator for exciting and compounding of alternating current generators. These inventors use the commutator for converting the high frequency stator currents into rotor currents of such a frequency as to obtain an inducing magnetic field which is constant both in magnitude and direction. In machines built according to this principle the armature reaction on non-inductive load will be completely compensated for by the induced currents, and therefore the fall in

terminal pressure under these conditions will be due only to the ohmic and inductive drop of the windings. To compensate also for these and for the wattless load currents, the same commutator in conjunction with current transformers is used for introducing the compound excitation. In this manner, even over-compounding can be obtained if desired. For further details of these schemes, the author has to refer to some recent publications, which fully cover the ground.*

While theoretically these last arrangements are undoubtedly very attractive, practical operation only can prove whether all the claims brought forth by the inventors can be realized.

In concluding, the author wishes to express his thanks to his assistant, Mr. F. H. Clough, for the help given in preparing this paper.

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* "The Electrician," July 3rd & 10th, 1903. "Eborall: On Induction Mach.," &c.

"The Electrician," October 2nd, 1903. Heyland: On the Compensation and Compounding of Alternating Current Generators."

"Transactions of the American I. E. E.," June & July, 1903. "Garfield, Lataur: The Compounding of Self-excited Alternating Current Generators."

DISCUSSION.

Prof. Marchant

Professor E. W. MARCHANT said—I think that the Society is to be congratulated on having such an interesting paper given this evening.

There are a number of points which have struck me as I have listened to the paper.

The first one which occurs to my mind is with regard to the statement made on page 143, that the best method of specifying the inherent regulation for machines is to specify for a given percentage rise in the terminal voltage instead of for a given fall.

That is, I suppose, a recommendation simply in accordance with the practice adopted in America, but looking at the matter with a perfectly open mind, it would appear that specifying for the fall was the better method, because the fall given in the table on page 150 is 19 per cent., whereas the rise is only 10 per cent., and therefore it is very much simpler to see whether or not the specification has been observed with a fall than with a rise.

With reference to the diagram given on page 154, showing the regulation characteristic for constant power and constant current, two points are shown, *a a* and *b b*, and on looking at the curves, I should imagine that the point *a a* was one in which the machine was in an unstable position, and *b b* was a point where you had a stable condition of working on a circuit regulated automatically to receive constant power and constant current.

Coming next to the regulation of unbalanced circuits, of course, in all the methods which have been described to-night, the regulation cannot obviously value account of want of balance in the phases, but in the Heyland arrangement, which has not been described, some attempt is made at compounding for unbalanced currents. The three-phase currents are led into the rotor through a commutator, and if the currents in the phases differ, it is possible to regulate the voltage on the phase where the heavy current flows without affecting the voltage on the other phases.

Turning to page 160, with reference to the inductive drop for overhead conductors. Surely the ratio of the ohmic to the inductive drop is constant. I should like to ask whether it is possible with a regulation similar to that which the author has described, to regulate so as to get over-compounding for loads of low power factor. I should think that it would be possible to do so. The magnetism which the P.D. coil of the regulator lags very nearly 90 degrees behind

the applied pressure, and that due to the current coil is in phase approximately with the current, if therefore the current lags much behind the applied P.D., its demagnetizing effect and the "P.D." magnetic strain will be greater than if the two magnetisations differed in phase by 90 degrees, *i.e.*, if P.D. and current were in phase. Prof. Marchant

I do not want to make criticisms that are too minute, but I should like to ask, with respect to the author's statement on page 162, whether 71 per cent. is the best figure to adopt. Theoretically, it is the best, if the synchronous motor is proportioned to the load and the circuit, but where the synchronous motor has to carry a load, it is surely best to over-excite it so as to get the proper amount of leading current to balance the lagging current in the circuit, independently of the exact ratio between the leading current and the total current.

I was very much interested in seeing the effect which was produced at Niagara with synchronous generators. I did not know that the hunting of synchronous motors could be prevented more or less by the action of induction motors on the same circuit.

Now coming to what I take to be the real point; the use of pulsating currents for regulating the pressure, I must say, on looking at the thing first, I was pleased with the idea. It seemed to me that there are too many contacts and springs. I would like to ask the author if he has made any experiments with it to determine the life of the contacts. Another point that struck me about it, was that if you have field magnets in which there is a variation in the field current there must be a considerable loss in energy due to eddy currents. I should expect that if the variation were at all great in the field current you would have excessive heating of the pole cores and formers.

Mr. J. P. Kemp said—The author has raised a good many interesting points and it is to be hoped that the majority of them will be borne out in practice. Mr. Kemp

It has struck me, however, in looking at some of the diagrams, that compounding would probably mean a good deal of complication in the switchgear, but I notice that the author has referred more to machines varying from 75 K.W. to 200 K.W. capacity than to the larger generators of 1500 K.W. and over, which are now usually installed in modern power houses.

I took the trouble this morning to find out the percentage of variation in voltage on the bus-bars for wide variations of load on a 1500 K.W. generator running alone, and with a 16 per cent. variation of load there was not the least apparent variation on the bus-bar E.M.F.

Mr. Kemp The machines referred to are just ordinary H.T. three-phase generators.

I should think that the compounding of such alternators would be very difficult indeed, and of course it is highly essential that the switchgear and connections generally should be kept as simple as possible. Compounding might be of some advantage in small installations where the plant has practically to look after itself, but in most large power houses it is absolutely necessary to have an attendant on the switchboard, and after performing the switching in, &c., his principal duty is to control the E.M.F. of the supply. This does not necessitate much attention, and I am strongly inclined to the opinion that in such cases compounding would be superfluous.

The author has referred to some types of exciters, and it is not very clear whether he refers to separately driven exciters or those which are driven by the alternators themselves.

With regard to the method of obtaining a power factor of unity, which Dr. Marchant states is practised in Niagara, I may mention that the same practice is also common in this country, and notably in Stuart Street Station, Manchester, the sub-station machines are mostly of the synchronous type, and adjustment of the power factor is readily effected.

I should be glad to know the author's views on the matter of fuses for H.T. three-phase alternators, if he considers them to be necessary, and how they are to carry the short circuiting current, if as usually arranged they blow with less than a 100 per cent. increase of the full load current.

Before concluding, I should like to express my appreciation of the author's very interesting paper.

Mr. Fierz Mr. J. Fierz said—Dr. Marchant mentioned the question of specifying regulation. The author says that the rise in voltage should be stated instead of the drop. From a designer's point of view I cannot ask better than that, it is the more easy way. The author, however, states that in order to prevent the designer from getting the small rise only by exaggerated saturation, the short circuit current should be $2\frac{1}{4}$ to 3 times the normal current. So it seems it is justifiable to ask for another specification. I might perhaps suggest here, that in specifying regulation, something between would be possible, for instance, specifying the drop as being the difference between the no load voltage and the full load voltage with excitation corresponding to half load. This really combines the two.

The author seems to be very sceptical on the question of com-

pounding alternators mentioned under No. 4. (Self-excitation by means of rectified or low periodicity alternating currents). My Company has taken up this matter, and I have some machines under construction. I hope to be able to publish some actual results in the near future. Mr. Fierz

There has been some discussion in the papers about the cost of this kind of machinery, but I do not think it is a question to be raised here. As long as the compounding alternator fulfils its requirements, the cost is not the only consideration. Besides, I think the author is wrong in thinking that the cost comes out higher than that of any other system.

Mr. R. S. McLeod said—I should like to ask the author whether the extra cost of higher regulation is made up by the bigger ampere turns which you get in the armature and whether there is any data available as to the performance of these alternators running in parallel. Mr. McLeod

Mr. Eustace Thomas said—I was interested in the figures given on page 151 for the percentage regulation recommended. The General Electric Company of America, four or five years ago, deprecated such low values and recommended higher figures. As the author is well acquainted with their experience, his views are interesting, but one is forced to wonder if in time these values will go down still lower and approach more nearly the old English practice. Mr. Thomas

In connection with the question of voltage regulation in alternating current systems, I am tempted to ask the author the results of his latest experience where rotary converters or motor generators are used. Some years ago difficulty was found in parallel running with rotary converters, and I had some experience of this, both in the States and here. Apart from the great importance of regular driving of the generators, the voltage variation on the lines was considered to have considerable weight, and it was considered wise to limit the resistance drop to 5 per cent., and the inductive drop to 10 per cent., though in certain cases as much as double these figures had to be put up with on long transmissions. What are the author's views and those of the General Electrical Company of America on this question, with their latest experience?

Mr. Julius Frith said—In connection with the running of synchronous machines and asynchronous machines together, it is pointed out that by this means you can get a power factor of unity. Now on page 148, the diagram, I think, shows a good reason why you should not. Look at the difference in voltage that would occur if you Mr. Frith

Mr. Frith were trying to get 100 per cent., and got a little way from that, whereas if you aim at 95 per cent. you get on to the other group of curves, and a small variation in power factor does not make nearly so much trouble in the running of the machine. I should think at Niagara they have been trying to get too near to the 100 per cent.

With reference to short circuit current, $2\frac{1}{2}$ times the normal seems to me to be low. A machine that has to stand large fluctuating overloads does not want its voltage cut down to zero.

Again, it seems to me very doubtful whether any good is done by fluctuating the exciting current. All these methods of regulation of voltage by fluctuation seem to me to be dangerous, on account of hysteresis and eddy current loss in the magnets.

Then, again, as to providing the exciter with slip rings for compounding, is not that equivalent to a rotary converter run from voltage supplied by a current transformer and really acting as a booster in the exciting circuit, varying the excitation according to the load going out of the station? As it is running synchronously it may or may not be coupled to the alternator.

Mr. Wilson Mr. H. W. Wilson said—I was very much interested in the accounts which the author gives of the various automatic methods of regulating voltage, and as regards the first method, there is an interesting example in Liverpool at the Liverpool Grain Storage and Transit Co.'s works. They have a three-phase installation with a load practically all motors, and the variations in load are not very excessive, and I find that the automatic regulating apparatus in use there is exactly the same as that described on page 165 of the paper, and they get very good results indeed. Of course there is a considerable time interval before the voltage comes back to normal, but still, for a motor load, I should think that the results given are satisfactory enough.

As regards the variation you get on small generators with fluctuating load, I was making some experiments twelve months ago and we were getting very excessive variations in load. The plant consisted of a 60 or 70 K.W. generator driving a motor of 50 H.P. The actual H.P. varied between 30 and 115. Well, on that machine the excitation voltage was kept constant, and the voltage variation was not more than 20 volts for the full load variation, and I should think that for conditions of that kind, the regulation described on page 165 would be quite good enough.

As regards the "Tirril" regulator, I have recently seen another regulator which is working in Liverpool, which is similar and which gives very good results.

I should like to know whether the author has any figures as to how closely the Tirril regulator will act, and also as to whether there is any limit in the capacity of the machinery that this regulator will control. I understand that the Tirril regulator might be used to control the voltage in a station of any size. Mr. Wilson

Mr. MEYER, in reply, said—I will endeavour to answer the questions in the order in which they are raised, but owing to the large number of them, my reply to each point must necessarily be brief. Mr. Meyer

First, in reply to Dr. Marchant :—My reasons for strongly recommending that the regulation should be specified as rise in voltage instead of fall, is based chiefly on commercial considerations. In England the manufacturers have to compete almost in all cases with American and Continental machinery. Now in both these countries the rise in voltage method has been standardized by the representative Engineering bodies, and figures on this basis are being put forward, and unless the buyer is thoroughly conversant with the difference between the two methods, his specifications are apt to call for figures which, as shown in the paper, lead to uneconomical design. Aside from this, it seems strongly desirable to aim at an international standard in technical expressions. Furthermore, it may often be difficult to test machines according to the fall in volts method if loads of low power factor are specified, as the armature reaction under such conditions will be apt to destroy the field almost entirely.

In regard to the question of stability of curve 5, page 154, Dr. Marchant seems to have in mind self-excited machines, which of course do become unstable under such conditions, but where the excitation is independent, any part of the curve represents stable conditions.

Referring now to the next point, I quite admit that Heyland's method of compounding ought to take care of an unbalanced load, but unfortunately this method—as recently pointed out by me in the "Electrician" — is attended by complications which limit its commercial usefulness.

As to the remarks dealing with the line drop, it is of course correct that the ratio of ohmic drop to inductive drop is constant, but the effect on the voltage is considerably influenced by the power factor, since the inductive drop is much the larger of the two, therefore the straight line assumption, as made in the paper, is only an approximation.

In regard to over-compounding for inductive loads with the described automatic voltage regulator, I can confirm Dr. Marchant's

Mr. Meyer views in this respect. In fact, it is used in this capacity in a number of plants.

Next to compensation by means of synchronous motors, I may say that my recommendations naturally referred to a system in which the amount of wattless current for which compensation is wanted, is known beforehand—not to a system where this is a variable quantity.

Finally, Dr. Marchant anticipates detrimental eddy currents due to the pulsating nature of the exciter field current. In this respect his fears, as shown in practice, are ungrounded, due to the rapidity with which the pulsations take place. For instance, a lamp across the exciter terminal will ordinarily show a steady light, and only when the conditions of the system change this will be momentarily indicated by a higher or lower incandescence of the lamp.

Referring to Mr. Kemp :—While I agree that commercially, compounding of generators is of greater value for small plant than for large ones, there is no reason why the described arrangement of automatic compounding should not be used to good advantage in the latter case, particularly where lighting and power is taken from the same busbars. The complications with the device in question would be hardly appreciable. In regard to fuses in generator circuit, while this is somewhat outside of the scope of the paper, in my opinion no fuses whatever should be used for high tension alternating current generators.

Referring to Mr. Fierz's suggestions :—To introduce still another method for specifying the regulation of an alternating current generator. This in my opinion would have the same objections as using the fall in volts method, *i.e.*, it would tend to confuse the customer, and introduce a standard differing from that of the rest of the world. In regard to the Heyland generators, I am glad to hear such promising hopes expressed by Mr. Fierz. I, myself, am somewhat sceptical about the usefulness of this type of alternator, except in small sizes and for high speed machines. In regard to the cost of the Heyland machines, I have definite proof that this comes out considerably higher, at least if I can rely on the cost figures published by the English agents of this class of machine.

Referring to Mr. R. S. McLeod :—The extra cost for machines with better regulation, to which I suppose the question refers, is due to the larger amount of material, both copper and iron, required. The parallel operation of such machines with very close regulation, is accompanied by considerable difficulties, as their inherent

stability is considerably less than with machines of poorer regulation. Mr. Meyer

With regard to Mr. Thomas' remarks :—While I regret to be unable to give here the opinion of the General Electric Co., of America, which firm I left five years ago, the paper represents solely my personal views, and these—in regard to the question of allowable drop in rotary converter installations, may be expressed as follows :—While the improved experience in designing rotary converters has considerably lessened the importance of this point, it still is well to adhere to some restriction in this respect, where high frequency converters are used. Here I should like to suggest as limiting figure, a total drop, ohmic and inductive, of about 10 per cent.

With regard to Mr. Firth's remarks :—I do not quite understand their trend. As necessarily when the machine is running near unity power factor, a much larger change in the amount of lagging current of the system is necessary to produce a given change in power factor than when the machine is running at a lower factor, and therefore his explanation for the troubles experienced at Niagara would hardly seem to hold good.

In regard to the amount of short-circuiting current, the recommended value of $2\frac{1}{2}$ times full load current of course refers to the no load excitation, and certainly there are no commercial plants where the load would vary from no load to twice full load. Therefore, I do not think my figure can be objected to on the grounds given, since with full load excitation it would naturally be considerably larger.

Referring to Mr. Wilson's remarks :—The objection to the regulator referred to on page 165, is its tendency to hunt, and while I have seen it successfully used in lighting plants, where the load changes very gradually, I cannot see how it can be of much use in power plants, since the voltage drop caused by the starting of large motors will be such as to interfere with the running of the rest of the plant before the regulator has a chance to act.

In regard to the maximum capacity of the generators for which the new voltage regulator described can be used, there is really no limit. The only addition which has to be made to the accessories of the regulator, is a condenser section for about every 1000-K.W. generator capacity. The regulator acts very quickly, and keeps the potential practically dead constant, or, if desired, can even be made to over-compound up to 10 per cent. for line losses.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

SEVENTH MEETING—27TH JANUARY, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E., PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz.:—Messrs. T. M. FOWKE, W. TURNBULL GRAY, J. W. HOWARTH, F. L. MONKHOUSE, WILLIAM NORRIS and W. G. WALLACE.

INDUCTION MOTORS.

By PROFESSOR E. W. MARCHANT, D.Sc., A.M.I.E.E.

IN reading before you a paper on the subject of Induction Motors I feel that a certain amount of apology is due, because in such a paper it is very difficult to find anything that is absolutely new. I think, however, that a description of recent developments should be of interest to many engineers on account of the great progress that has been made in the last few years in the design of this kind of electrical machinery. It may be interesting to mention, in the first instance, one or two points in the history of the development of these motors.

The fundamental experiments on which the action of them is based were performed in 1825 by Arago. The experiment that he made was with a pivoted copper disc below which he placed a revolving steel magnet. He found that when this magnet was rotating, the disc rotated with it, the action being due to the induced currents in the disc. The next step in the progress of the development of the motor was made in the year 1879, when Mr. Walter Bailey exhibited to the Physical Society of London a model which can justly be described as the first induction motor. In this model Mr. Bailey had four straight

cylindrical magnets placed parallel with one another, their centre points being arranged to lie at the four corners of a square. These magnets could be excited in turn by dry cells, and over the top of them was suspended a flat circular disc of copper. The magnets were excited in succession, the effect being to produce a uniform or nearly uniform rotating magnetic field; when this was done the copper disc rotated with the field. At the time at which that paper was written it is interesting to note that Professor Guthrie jokingly asked how much power it was expected the motor would give.* Among others who have helped with the development of these motors must be named Monsieur M. Duprez, who was the first to produce the rotating field with artificial two-phase current.

One of the most indefatigable pioneers was, however, Professor G. Ferraris, who, in 1887 made a motor which very closely resembles in most essential characteristics the modern induction motor. The rotating field was produced by the action of two-phase currents, and the rotating part was made of a cylindrical mass or block of copper. It would be impossible to give even the briefest outline history or to attempt to give the history of these motors without mentioning the work of Nikola Tesla. This inventor, in 1886, produced induction motors of considerable power, in which the rotating part was of cylindrical shape carrying straight copper conductors, through which currents were induced, the stationary parts being made up of a number of laminated poles, excited by the action of two-phase currents.

CONSTRUCTION.

At the present time the construction of induction motors has become practically standardized, motors which are made by different firms, differ only in few, and in many cases, unimportant details. The induction motor consists, as all other motors consist, of two parts, the fixed part, called the stator, and the moving part, called the rotor. I shall deal with these two parts successively. The stators of these motors are made up of a number of hollow iron discs or stampings of circular shape, on the inner periphery of which a number of holes or slots are punched, in which the conductors carrying the exciting current are placed. The stampings employed are usually not less than twenty mils. in thickness. They are stamped from the sheet metal as accurately as possible and are then assembled on an iron mandril. After this, end rings are placed on the mandril and the whole is

* S. P. Thompson: "Polyphase Currents," page 439.

rivetted together. It is important that the iron should not be tooled more than is absolutely necessary, as this deteriorates its quality, and moreover entails a considerable loss due to eddy currents. The stator core discs, with the end plates are then fastened tightly in their containing case, either by bolts or by shrinking the case on to the discs. On to this a cover is bolted, which carries the end plates which support the bearings of the motor. It is only in very large sizes that a separate bed-plate is employed. One of the most important points in the construction of the stator is the shape of the holes or slots in which the conductors are placed (Fig. 1). Some American firms, notably

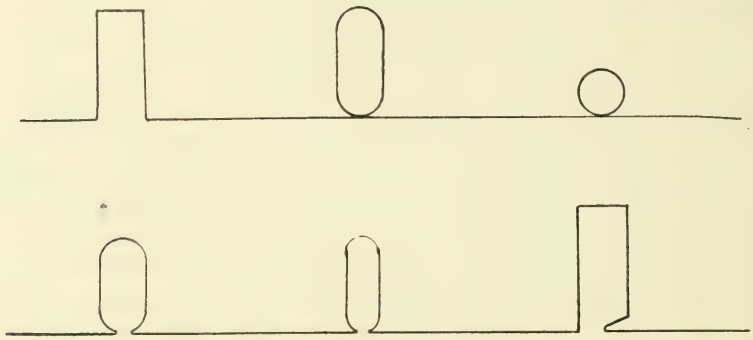


Fig 1

the Westinghouse Company, employ straight slots; others, including nearly all the Continental and English makers, use slots that are nearly closed, or else holes with a very narrow bridge-piece. The disadvantage of using holes is that the bridge piece serves as a leakage path for the magnetic flux produced by the stator conductors. On the other hand the use of holes gives to the interior of the stator a perfectly smooth surface, which can, if necessary, be turned with great accuracy, the magnetising current being thus reduced to a minimum. Hence, it is possible for hole wound stators to work with smaller clearances between stator and rotor than could be done with stators having semi-closed slots. The majority of machines, however, are built with semi-closed slots. The winding of the stator is precisely similar to that of an ordinary two- or three-phase alternator, but for convenience in winding only alternating poles are wound. The number of slots per hole is usually from four to six, in order that the flux produced may be distributed as uniformly as possible.

The other essential part of the motor is the rotor. This consists of a number of circular core plates, such as are used in the armatures of ordinary direct current machines. The thickness of the rotor core discs is generally considerably greater than that of the stator stampings, and on the outer periphery are stamped the holes which carry the rotor conductors. The shape of the holes or slots is generally similar to that used on the stator. It is important, however, that the number of the holes should not bear any simple proportion to the number on the stator, otherwise, when the motor is started, cogging will take place due to direct attraction between the stator and the rotor teeth. The clearance that is allowed between the stator and the rotor is, in these motors, exceedingly small. To give some examples:—in a motor of 6 H.P. with a diameter of 25 centimetres, the air gap is only half a millimetre. In a machine made by Messrs. Brown Boveri, of 300 H.P., the diameter is 8 feet, and the air gap is ·2 inches, and generally speaking, the air gap is about $\frac{1}{500}$th of the diameter of the core; the necessity of accurate centreing of the rotor is therefore obvious. The performance of a rotor can be considerably improved, according to Mr. Eborall, by arranging that the rotor and stator slots are not parallel, but are staggered slightly on one another. In the construction of the rotor winding there are two distinct modifications. In a small motor the winding consists simply of a number of conductors placed in the rotor slots, the ends of which are all bolted or sweated into end rings. This is called the squirrel cage form of rotor, and its advantages may be briefly classified as follows:—(1) Great simplicity of construction; (2) No rubbing conductors; (3) Simplicity of operation; (4) Independence between form of rotor and the number of stator poles. This type, however, for larger motors, generally becomes inadmissible, on account of the very heavy starting currents that are required if a torque, in any way equal to a full load torque, is to be obtained. The reason for the small starting torque with this type is the large time constant of the rotor circuits. This produces a difference in phase between current and induced E.M.F. at starting (when the frequency of the rotor currents is high) and thus some of the conductors carrying large induced currents lie outside the field producing them, or even in a field of the wrong sign, *i.e.*, producing a reverse torque.

In order to reduce the time constant of the rotor circuits, several devices have been introduced; one is to make the end rings of German silver, another used by Kolben, is to connect all the ends of the rotor conductors with radial strips of copper which are sweated into a

short circuiting ring of small diameter made of bronze. This device, however, while increasing the starting torque, at the same time diminishes the efficiency of running, and where that is a matter of importance, it is far better to use wound rotors. In the second type of rotor winding, the construction is similar to that used in the armature of a three-phase star or mesh wound generator. The coils are wound in slots and the ends of them are brought out to slip rings, and can be connected with suitable star wound resistances. Thus when a motor is starting, the resistance of the rotor circuit is high, consequently the time constant is small. By adjusting the value of resistances it is possible to obtain a full load, or even the maximum torque that the motor can exert at starting. This will be seen from the curves shown for some Westinghouse motors (see Fig. 2).

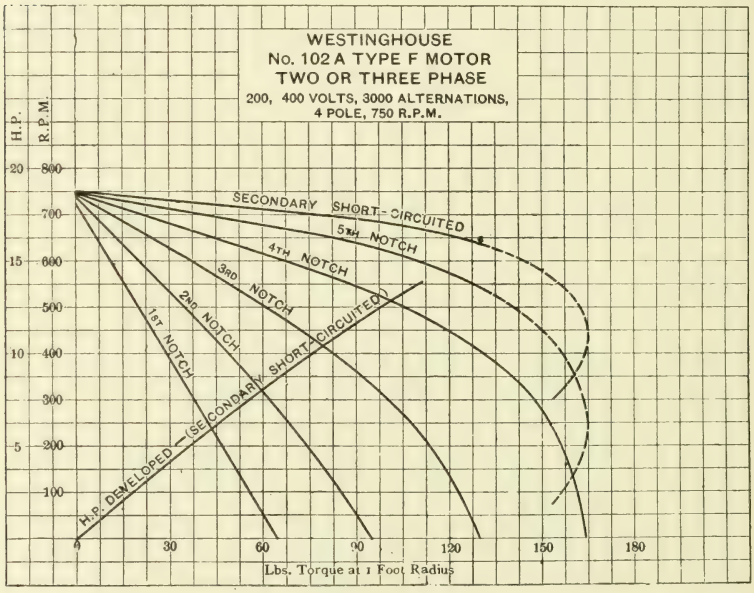


FIG. 2.

It may be of interest to give here some details of two typical motors which I have worked out. I append a table (see page 190) showing the details with working fluxes and current densities for two motors, one by the Allgemeine Elektricitäts Gesellschaft of Berlin, and the other by the Union Elektricitäts Gesellschaft, also of Berlin (see Fig. 3).

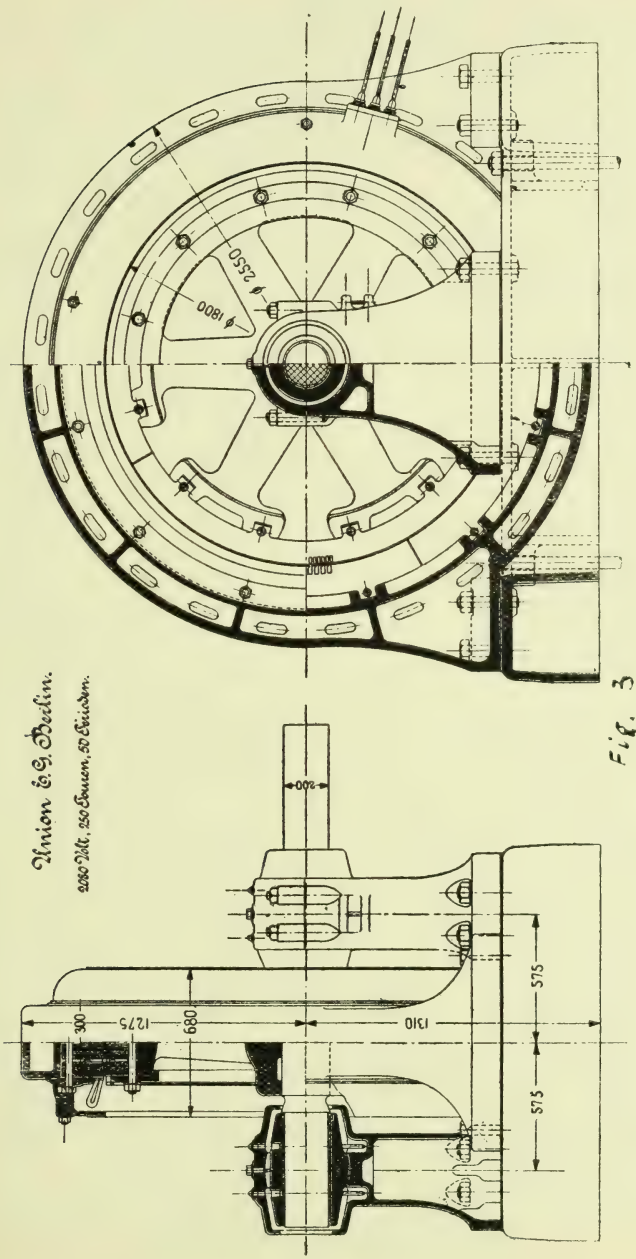

Union A.G. Berlin.
2280 Volt, 250 Umdr., 50 Period.
200
300
1275
680
1310
575
575
ϕ 1800
ϕ 2550

Fig. 3

TABLE

Showing the Details with Working Fluxes and Current Densities for Two Motors.

	A.E.G.	U.E.G.
Horse power	30	250
Watts per H.P.	890	860
Kilowatts	267	215
Frequency	50	50
Number of phases	3	3
Synchronous speed	1,000	250
Volts between rings	500	2,080
Amperes per phase	31	68
No. of pairs of poles	3	12
Rotor diameter	17·3 ins.	71·1 ins.
Pole arc	9·05 ins.	9·3 ins.
Length of iron	4·18 ins.	10·63 ins.
Surface speed in feet per minute ...	4,530	4,650
Air gap...	·039 in.	·079 in.
Flux per pole, no load	1·2 × 10	1·7 × 10
Flux density in stator per square in.	32,000	27,100
Arrangement	Y	△
Windings in series per phase ...	115	576
Current density in amps. per sq. in.	1,550	1,420
Conductor dimensions	3 × ·091 diam.	3 × ·102 diam.
Slots per pole per phase	5	3
Total slots	90	216
Slot dimensions	·433 ins. × 1·14 ins.	·7 ins. × 1·74 ins.
Maximum induction in teeth ...	113,000	91,600
Depth of iron	2·56 ins.	4·1 in.
Rotor arrangement	Y	Squirrel cage
No. of phases	3	—
P.D. between rings when clamped...	103	—
Current per phase under load ...	150	—
Windings in series per phase ...	23	1—
Total No. of conductors	140	312
Total copper section	14 sq. ins.	121 sq. in.
Current density in rotor conductors	1,520	1,385
Conductor dimensions	·178 in. × ·59 in.	·355 in. × 79 in.
Slots per pole per phase	7	1
Slot dimensions	·236 in. × ·69 in.	·423 in. × ·945 in.
Max. induction density in teeth ...	95,500	79,000
Iron depth	1·89 ins.	3 ins.
Induction density in rotor core ...	49,500	29,600
No load current (amperes)	9·1	13·3
Short circuit current...	230	144
Weight per kilo. volt amps. iron ...	26·9 pounds	39·6 pounds
" " " copper	6·26 pounds	7·6 pounds

OPERATION OF INDUCTION MOTORS.

I have been able to collect a number of figures which have been supplied to me by different manufacturers, which enable a comparison to be made between the working of induction motors and ordinary direct current motors. I am also indebted to a paper recently published by Mr. Eborall on the subject of "Electric Traction with Polyphase Currents." *

In making the comparison it is necessary to consider the conditions that the motor has to work under. We can compare four points, (1) Starting torque, (2) Speed regulation, (3) Speed variation, and (4) Efficiency. Now, comparing the ordinary direct current motor with the induction motor it is obvious that as far as starting torque goes the shunt motor leads the way. It is almost impossible to get (with a single induction motor) a very large starting torque without the expenditure of a current very much larger than the full load current. In the average case, with squirrel cage rotors, the full load torque requires a current approximately three or four times the value of the full load current. The starting torque for traction purposes may, however, be very largely increased by using induction motors in tandem, or, as it is sometimes called, cascade. This method of operation has recently received considerable attention from Messrs. Ganz of Buda Pesth, who have equipped the railway at Valtellina with locomotives carrying induction motors working at 3000 volts, each locomotive carrying four motors which can be arranged in pairs at starting, and two of which only are used in running. The method of operation is fairly obvious. The rotor of the first motor is arranged with a three-phase winding, the ends of which are brought out to slip rings. These slip rings are connected with the stator of the second motor, which, in turn, is driven by the current induced, and the rotor of which is connected to the resistance. The effect of this arrangement is, practically to use at starting a motor which has half the number of poles of each of the motors employed. The greatest speed which can be obtained from motors connected in this way is half the full load speed of each motor. The frequency of the currents induced in the rotor of the first motor is that corresponding with the difference in speed between the rotating field and the rotating rotor. The speed of the rotating field, however, in the second motor must be equal to the difference in the two speeds already referred to in the first motor, and when the speed of the rotor in the second motor is equal or nearly equal to this it is obvious that the speed of the second rotor will

* "Electrician," Vol. LII., page 327, *et seq.*

be half that of the field in the first motor, the two rotors running at the same speed.

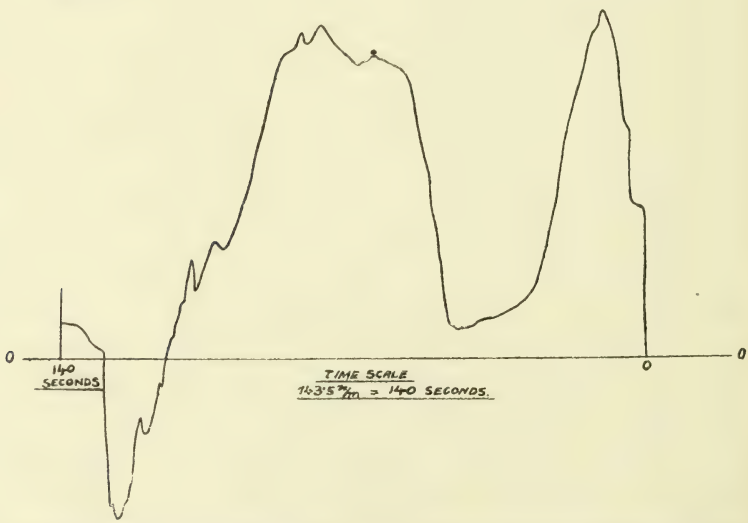
From some curves obtained by Mr. Kapp on the Valtellina Railway, which show the working results obtained with this arrangement of the motors, it will be seen that the acceleration is as great if not greater than that obtainable with direct current motors working under similar conditions, but that the power factor of the combination is low. A great advantage of this arrangement is that it can also be used to brake the motors when the train to which they are attached is running down hill over a considerable range of speed. The curve in Fig. 4 shows how energy may be given back by the motors to the lines under these conditions.

POWER AND ENERGY GIVEN TO LINE IN RUN V.

ENERGY SCALE 1 SQ m/m = 4·2 KW. SEC.,

POWER SCALE 1 m/m = 4·3 KW.

Fig. 4



Another device that is sometimes used for increasing starting torque on star wound motors is to connect them up in the first instance in mesh and subsequently to change over to the normal arrangement.

SPEED REGULATION.

The induction motor is one that essentially lends itself to maintaining a constant speed. The only or nearly the only practicable method

of obtaining speed variation is by introducing rotor resistance, a method which may be compared to the method of speed regulation with direct current motors by introducing rotor resistance in series with the armature. This is, of course, a very wasteful procedure, and generally speaking, where large speed regulations are necessary, induction motors are not suitable. Behn-Eschenberg* has recently described a comparatively simple switch by which the number of poles on the stator of the motor can be varied, and in that way the speed can be regulated (the speed of an induction motor is, of course, equal to the frequency of the supply divided by the number of pairs of poles with which the stator is wound). In railway work the disadvantage of the induction motor from this point of view is obvious, as the motor will take the train up steep grades at the same rate as along the level.

SPEED VARIATION FOR CHANGING LOAD.

Now coming to the third point—speed variation. The variation in speed of an induction motor under different loads can be made exceedingly small. In the best motors of large power, say of 100 horse power, the maximum slip will at full load amount to only some 3 per cent. of the no load speed, so that for driving machinery that is to be run at very constant speed it is obvious that induction motors are particularly suitable. The overload capacity also of motors of suitable design is very large, and in many motors running at 100 per cent. overload the speed variation amounts to only some 5 or 6 per cent. (See Fig. 2). Of course in smaller motors the speed variation is somewhat greater, but even in the case of a 5 or 6 horse power motor the slip does not exceed 10 per cent.

It may be interesting to note here that one of the earliest applications of induction motors in this country was in 1897, when a three-phase installation was placed in the warehouses of the Liverpool Grain Storage Co. For sub-station work, where a constant speed is required for driving motor generators, the induction motor possesses many advantages over the synchronous motor not the least of which is its inability to hunt.

EFFICIENCY.

As far as efficiency is concerned, there is little to choose between direct current and induction motors. On the whole the induction motor is perhaps slightly less efficient than the direct current. I

* Elekt. Zeits, Wien 20, pages 624-628.

have some figures* to illustrate this point, which may be given here :—

80 H.P. TRACTION MOTORS.

	Induction.	Direct Current.
Efficiency at full load	90 ...	88·5 per cent.
Efficiency at $\frac{3}{4}$ load	90 ..	87 "
Efficiency at $\frac{1}{2}$ load	90 ...	83 "
Efficiency at $1\frac{1}{4}$ load	89 ...	86 "

For motors of different powers at full load, the following figures, given by Mr. Earle, may be interesting :—

H.P.	Direct Current.	Polyphase.
$3\frac{1}{2}$ ...	82 per cent. ...	75
6 ...	85 " ...	80
10 ...	86 " ..	84
25 ...	91 " ...	88
50 ...	92 " ...	90
100 ...	92 " ...	91

These two sets of figures, though differing slightly between themselves, show that the efficiency of the two types is practically the same.

POWER FACTOR.

In all alternating current machinery it is eminently desirable that the apparatus used should have as high a power factor as possible. From this point of view the induction motor is less satisfactory than a direct current motor, since the power factor of the former is always less than unity, while that of the direct current motor is unity. The exact figures that can be obtained in ordinary work are shown by the following results. Taking the case of four motors, of one, two, three and five horse power, their power factors vary from 66 to 75 per cent. at half load, from 75 to 88 per cent. at full load, and from 70 to 88 per cent. at 50 per cent. over load. The following figures for motors of different powers may perhaps be useful. These refer to average motors of larger power working at full load :—

B. H.P.	Power Factor.
5 ...	·76
10 ...	·79
15 ...	·81
25 ...	·83
50 ...	·86
100 ...	·88

Much higher figures may be obtained in many motors.

* "Electrician," Vol. LII., page 325.

It is obvious, therefore, that with induction motors of small power the current that will be taken for a given voltage will be, on an average, some 15 per cent. more than that taken by a smaller direct current motor, and consequently the main required for feeding such motors would have to be of larger section than would otherwise be necessary. As, however, the copper required in transmitting a given power with a three-phase system is only 75 per cent. of that required for transmitting the same amount of power (power factor unity) at the same voltage, with direct current, the extra section does not materially affect the total cost of transmission.

The low power factor of the motors is, of course, not satisfactory from the point of view of the central station engineer, since loads of this kind mean less satisfactory pressure regulation of the generators.

Before leaving this subject of power factor, I must mention an exceedingly interesting and useful device recently described by Mr. Heyland,* by which a power factor of unity, or very nearly unity, can be obtained in an ordinary induction motor. The main part of the wattless current required by any motor is that necessary to produce a magnetisation in the stator and rotor core. If that magnetisation current is sent through the stator, the necessary current is one of high frequency, and consequently the inductance of the stator coils to this current necessitates the use of a large electromotive force. If, however, the current necessary for producing magnetisation is supplied to the rotor, that current will only be of a frequency corresponding to the slip between the rotor and revolving field, *i.e.*, of only some 5 or 10 per cent. of the main frequency, consequently, if the magnetisation current is supplied by the rotor, the potential difference that is necessary to send the current through the rotor will be that which is necessary to overcome the ohmic resistance of the rotor conductors, together with the E.M.F. that is necessary to produce the leakage flux in the stator and rotor. Since the frequency is low this E.M.F. will also be small. The way in which this is effected in the Heyland motor, is by the use of a special commutator. This commutator has in a two-pole motor pressing against it three brushes. The magnetisation current is fed in through a step-down transformer which is excited from the main circuit, and the commutator is connected at three equi-distant points to the ends of three-phase rotor windings R. The segments are connected together by low resistance strips, which in the actual motor are extensions of the original commutator bars. The use of the short circuiting strips is

* "Electrician," Vol. XLVII, page 627, Vol. XLV, page 530.

to prevent sparking at the brushes, and also to damp down the unavoidable fluctuations that occur in every frequency changing arrangement. The advantages of exciting with a low frequency current have already been brought out, and in this motor it has been found actually possible to obtain a power factor of 100 per cent. for the whole range of working in the motor.

I regret that I am unable to show any results obtained with these motors, but they have not, so far as I can understand, yet reached a commercial form, and the manufacturers wish therefore not to publish any further details in connection with them.

SINGLE-PHASE INDUCTION MOTORS.

The obvious advantages of single-phase working for ordinary transmission are so numerous and great that the construction of single-phase motors has attracted perhaps more attention than any other in the domain of electrical machine design. The various single-phase motors that have been devised differ from each other in many essential charateristics, and since this paper is intended to describe only induction motors, I shall not attempt to go into the working of motors such as the series single-phase motor. The two types to which I shall pay the greatest attention are, firstly, the ordinary induction motor, and, secondly, those known as repulsion motors. Both of these types are, of course, strictly induction motors, since they are operated by the action of currents which are produced in the rotor, and not by currents which are led into the rotor from the external circuit.

ORDINARY INDUCTION MOTORS.

The construction of these motors differs in no essential feature from that of the ordinary three-phase or two-phase motor; in fact, any induction motor designed for a three-phase circuit can be used on a single-phase circuit if one of these phases is connected to the single-phase system and the others are disconnected. The disadvantage of the single-phase motor is that when the rotor is stationary there is no driving torque at all acting on it, and consequently it is important to use these motors with some special starting device. The starting devices are numerous, and it would be impossible to more than mention some of the most important of them.

The greater number depend for their action on the use of an auxiliary winding on the stator, generally on the use of the equivalent to a two-phase winding. The main or running winding is wound in the

same way as that of the one-phase of the ordinary two or three-phase motor, except that the single winding covers a larger fraction of the total circumference of the pole. Along with this an auxiliary or starting winding is arranged, which takes the place of the second-phase winding in the two-phase motor. Sometimes an equivalent three-phase winding is employed, but this arrangement is less frequently met with than the two-phase. The starting winding usually consists of a smaller number of conductors than the main winding, and is fed in direct from the main circuit through some auxiliary inductance or capacity.

The essential distinction between the main current and the starting current must be a difference in phase between them. That difference in phase may be produced most satisfactorily by putting in series with the starting coils a capacity. If a large induction is used outside the motor the difference in phase between the starting and running currents must necessarily be small, because the running coils themselves possess a very considerable inductance, and at starting the lag may be something approaching 40 or 50 degrees, so that even assuming that the maximum lag (90 degrees) was obtained in the starting coil, the greatest phase difference that would be possible would be some 40 or 50 degrees. By the use of capacities greater phase differences are obtained, because in that case the starting current is made to lead on the applied potential, while the running current lags behind it. Unfortunately, condensers of sufficiently large capacity, at a reasonable price, are hardly obtainable, and, moreover, when obtained are not generally found absolutely reliable, so that starting devices which depend upon their action have not met with very great favour.

Another method that is sometimes used with large single-phase induction motors, is to start the motor up by an auxiliary single-phase motor, and thus obviate the necessity of putting the starting winding on the larger motor. One interesting method of starting these motors was described some three years ago in a paper by Mr. Eborall,* devised by Mr. Heyland, in which the necessary difference in phase was produced in the motor itself without any auxiliary resistance at all. Instead of winding the starting and running coils in slots of similar shape, the starting coil was arranged in one or two large holes in the stator core, the holes having fairly thick bridges on their inner periphery. The currents in these starting coils were made to lag in phase by an angle of considerable amount, because the

*"Institution Electrical Engineers Proc.," Vol. XXIX., page 799.

inductance of such coils was very much greater than that of coils wound in the ordinary slots due to the large magnetic leakage across the bridges. In order to produce the equivalent to a rotating field, the starting current was made considerably greater than the running current. These motors were set to start with full load torque with only twice the normal full load current, but in a motor of this class which I have in my laboratory, which is of 6 horse power, the results I have been able to obtain have not altogether fulfilled this guarantee.

Coming next to the rotors of these motors, they are arranged in a very similar way to those of the ordinary two- or three-phase induction motor, and I need not therefore spend any time in describing their construction. It is important to bear in mind, however, that with a single-phase motor, running on a single-phase, the torque cannot be increased at lower speeds by inserting rotor resistance. The action of the motor differs from that of the three-phase motor in that part of the field which acts on the rotor and produces the driving torque is due to the current in the rotor itself. In this motor we have, in fact, a rotating field, which is partly produced by the single-phase current in the stator and the other component by currents in the rotor itself, so that if resistance is placed in the rotor circuit, the effect is to reduce the rotor current and consequently to reduce one component of the rotating field; thus, the effect of resistance is always to reduce the torque which the motor can exert. On the other hand, when the motor is starting, the resistance in series with the rotor is exceedingly useful for exactly the same reason that it is useful in the two- or three-phase motor.

Dealing now with the same points that were considered in the two- or three-phase motor, the operation may be very briefly described. (1) The starting torque. As far as this is concerned, the single-phase induction motor is a very bad one, and efficiency in this direction can only be obtained by the use of a complicated external device. (2) As regards speed regulation the single-phase induction motor is also unsatisfactory, for, as I have already stated, it is impossible to alter the speed for maximum torque by inserting rotor resistances, so that practically the motor will only run at one constant speed. The method also of changing the number of poles, which is, at best, a complicated one, is not easily applicable to the single-phase motor, since any change in the number of poles must be accompanied by a very large fall in torque, so that a single-phase induction motor must be run practically at a very constant speed if it is to work at anything like its full power. (3) Constancy of speed or speed variation.

In this point, also, the single-phase induction motor falls behind the two- or three-phase motor. The percentage slip for a given load for the single-phase motor working under given conditions is exactly double that of the same motor working as a two-phase. (4) The Efficiency. In this, also, the single-phase motor is unsatisfactory since the percentage loss in the rotor is exactly double that of the same loss in the case of the two- or three-phase motor power factors of these motors when running at ordinary loads vary between 60 and 80 per cent. for ordinary sizes, but the actual number of motors in use at the present day is not very great.

REPULSION MOTORS.

These motors have, within the last year, received considerable attention, or rather it would perhaps be better to say that within the last year several descriptions of new single-phase motors have appeared. In a motor of this type, the field system may be either of the form used in the ordinary direct current motor with laminated poles, or may be, as in the motor described by M. Marius Latour,* distributed over the surface of a core, similar to the stator of an ordinary induction motor. The rotor or moving part consists of the ordinary drum wound or open coil armature with commutator. Against the commutator press brushes which are short circuited. The coils just leaving the pole have currents induced in them in such a direction that they are repelled from the pole just as the rings in Elihu Thomson's experiments were repelled from poles fed with alternating currents.

In the motor described by Mr. Cramp this principle was used, and the rotor was made of special form with an open drum winding, having a coil width equal to that of the pole, the pole width being half the pole pitch. These coils were connected with the commutator in the same way as the ordinary open coil armature; the coils were short circuited by brushes of considerable width, that is, sufficient to cover either four or six segments, and were short circuited only when in a position of maximum efficiency.

Although no curves showing the operation of these motors have been given, it is stated that with a power factor of ·7 it is possible to get a full load starting torque with very little more current than is required for full load running. The speed of these motors can be regulated within considerable limits by shifting round the short circuiting brushes, but the power factor of them can never, according to

* "Electrician," Vol. LI., page 490.

Mr. Cramp, exceed from the ·7 to the ·8 without considerable loss of torque. There is one point of considerable interest in connection with this motor, namely, that what is known as the exponential term in the equation for determining the flow of current in a circuit to which an E.M.F. suddenly applied becomes of some importance and affects the running of the motor. He found it necessary, in order to get his motor to run satisfactorily, to reduce the number of turns per coil on the rotor to one or two, since in many of the motors first tried, the action altogether failed from this cause. Another motor which I may mention, in which the same principle is involved, is that designed by Marius Latour, which differs in no essential characteristic as far as the rotor is concerned, from the ordinary direct current motor. In the stator, as already mentioned, the winding is distributed over the inner periphery instead of being concentrated at the poles. This is found to have an extremely beneficial influence on the work of the motor, and M. Latour has been able, by using this arrangement, to obtain motors which do not spark perceptibly at their commutators and yet which give very satisfactory starting and running torques.

In the Ferranti-Schüler* motor, which is one in which the induction principle is combined with that of the repulsion motor, an armature is used, such as is employed in an ordinary direct current machine; connected to different points on the windings are wires which are led to slip rings. These rings are connected in turn to a three-phase resistance which can be put into the circuit while the motor is running up to speed. Brushes are arranged to press against the commutator of the motor (for example, in a two-pole motor two brushes are used) and these are short circuited. When starting, the action is exactly similar to that in the Cramp repulsion motor, but as with that motor the torque falls off rapidly with increase of speed. As, however, the speed increases the induction action comes into play, with the result that the combined action produces a resultant torque which only varies by some 15 per cent. for a variation in speed from 0 to 80 per cent. of the maximum.

From some curves, recently published, illustrating the working of this motor, it will be seen that the torque obtained is nearly double the full load torque with a consumption of current less than twice the full load current. These motors are now being made by Messrs. Lahmeyer, and it would seem that in single-phase circuits they should be exceedingly useful.

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*"Electrician," Vol. LII., page 487.

Another very similar mixed motor was devised by, I think, Professor Arnold, and is now made by the Wagner Manufacturing Co. of New York. In this motor, the action at starting is that of the repulsion motor. When the motor has attained its full speed or nearly its full speed the action changes to that of the ordinary induction motor, *i.e.*, the commutating segments are short circuited by a centrifugal switch, pressing a number of short circuiting lugs into slots cut in the radial commutator segments. In this way the power factor of the motor when running at nearly full speed is considerably improved, while the starting torque is increased to an extent impossible in a pure induction motor.

Although it does not exactly fall within the limits of this paper to describe anything but pure induction motors, I should just like to mention another form of motor which is also a mixed action motor. This is a combination of the repulsion motor and the ordinary series motor. This motor was described in a paper by Mr. Eborall in the "Electrician" for December 25th, 1903. In these motors, one of which was devised by Latour, and the other by Winter Eichberg, the stator is, in the Latour motor, similar to that of an induction motor, and in the Winter Eichberg to the continuous current motor, the rotor in both motors is the same as for an ordinary direct current armature. The commutator has four brushes pressing upon it, two short circuiting brushes placed in the position for greatest efficiency when acting as a repulsion motor, and the other two in a direction at right angles to this. The two brushes corresponding to the repulsion motor action are short circuited, while the other two are arranged in series with the stator winding. These motors are said to give excellent results; their power factor is very much higher than has been found on ordinary repulsion motors.

TESTING.

I should like, in concluding this paper, to make some mention of the methods of testing that are generally adopted for induction motors. In nearly every case nowadays the Heyland diagram is used for demonstrating the characteristics of a machine. The ease with which it can be drawn and the simplicity of the tests required to draw it, make it exceedingly useful for ordinary practical work. I need not spend time in explaining the way in which the diagram can be drawn, since that must be known to all who have had anything to do with induction motors. But I thought it would be of interest to experiment

with some motors I have in my laboratory to see how far the results obtained with the Heyland diagram agreed with those obtained by ordinary brake tests. I append some curves (see Fig. 5), which show the

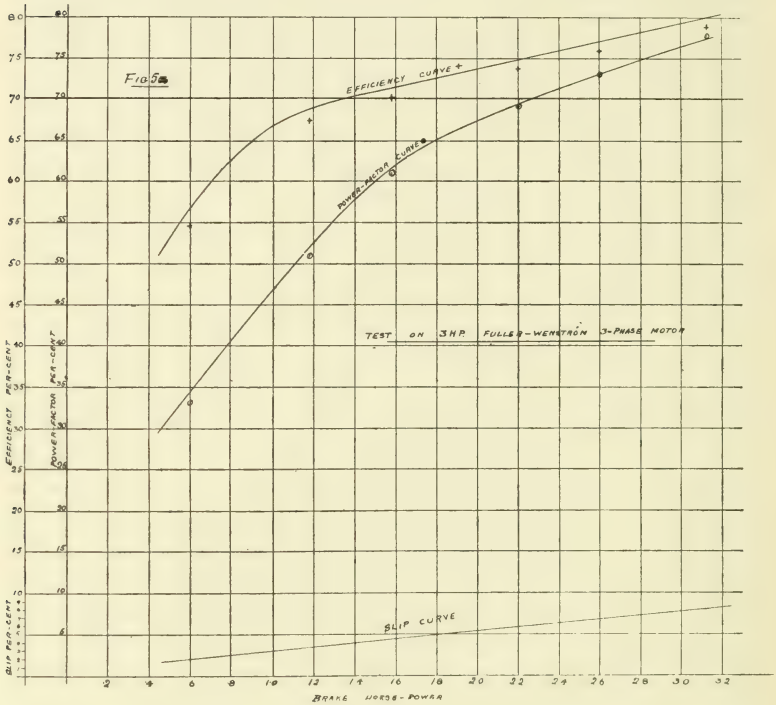


FIG. 5.

relation between B.H.P. and efficiency and power factor for a 3 H.P. motor obtained by actual experiment. On the power factor and efficiency curves are shown points which were obtained by calculation from the Heyland diagram (see Fig. 6), and it will be seen that the accordance between these two sets of results is exceedingly close, showing that the Heyland diagram is really a very reliable device for quickly obtaining the characteristic properties of any motor.

I should like, in conclusion, to express my thanks to those firms that have been good enough to supply me with test results and drawings of motors of their manufacture, in particular to Messrs. Ganz of Buda Pesth, Messrs. Siemens, the British Westinghouse Co., the British Thomson-Houston Co., and to Messrs. Witting, Eborall and Co. I wish to express my thanks to Mr. Worrall for his assistance in obtaining

the experimental results incorporated in this paper and for drawing the curves, and also to Mr. Morgan who designed and made the brake used in the tests, and who assisted in making the experiments.

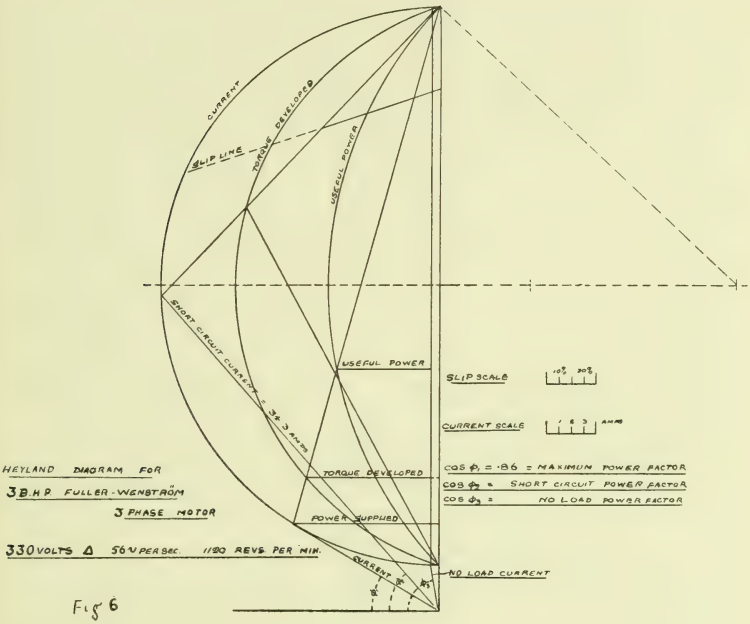


Fig 6

DISCUSSION.

Mr. Kemp

Mr. J. P. KEMP said—Dr. Marchant concluded his very interesting paper with an apology for its length, but I feel that I am expressing the opinion of all present by stating that our interest would still have been maintained had it been twice as long.

Although not mentioned by the author, the variations of brake horse power in three-phase motors is a matter which has of late come in for a good deal of attention, and I have frequently heard it stated that the B.H.P. varies as the square of the E.M.F. at motor terminals.

I presume, however, that this only holds true in cases where the frequency is constant, and the fall of pressure is due to resistance or impedance. In my experience, I have found pressure variations to be almost entirely due to the varying speed of generators in the power house, and this involves a proportionate variation in frequency.

Frequency is, of course, an important factor in impedance, and as the resistance of station windings is of comparatively little importance compared to reactance, the latter need only be considered.

I take it that reactance varies directly as the frequency, therefore I am of the opinion that in three-phase motors the B.H.P. does not in practice vary as the square of the E.M.F., and I should be very glad to know Dr. Marchant's views on the point.

As to the hunting of induction motors, I can mention one instance of hunting which may be of interest.

A large alternator was on load alone and excited by a small C.C. generator driven by an induction motor, which was in turn driven by the large alternator.

Something went wrong with the governor of the engine driving the alternator and the set commenced hunting violently, the speed varying rapidly from ten per cent. below to ten per cent. above the normal; the result was synchronous surging of all the substation machines, and much tribulation on the part of the induction motor driving the exciter.

The latter endeavoured, of course, to keep its slip as constant as possible, and, as the speed of the generator increased, the rotor of the induction motor sped up in almost similar proportion, but owing to a sudden drop in the speed of the generator the momentum of the rotor

carried it past synchronous speed and caused it momentarily to act as a generator; this, of course, caused it to slow up, and thereby reduced the excitation of the generator, resulting in a total collapse of the E.M.F. of the latter. Mr. Kemp

The induction motor stopped immediately and the supply was restored in less than a minute by running up another generator excited from the C.C. lighting bus bars.

From the acceleration curves of the cascade arrangement of induction motors, I take it that their behaviour when connected in this manner is in some respects analagous to the series parallel arrangement of direct current motors; in fact the curves shown are in many respects similar to those which were obtained some time ago during tests on the Liverpool Overhead Railway.

The compensating devices designed by Heyland are exceedingly ingenious, but I am afraid such devices will rob the induction motor of the simplicity which has hitherto been one of its principal recommendations.

A very great advantage with the induction motor is the fact that it has no commutator, and some years ago, when commutators were not so perfect as they are now, we looked forward to the introduction of the induction motor as an undisguised blessing.

The matter of single-phase motors for traction work is very interesting, and we have heard a great deal of them recently. There is one point, however, which will, I am afraid, militate somewhat against their general adoption for traction work, and that is the impedance of the track return. I think I have heard it stated that with certain frequencies, the impedance of track is twenty times greater than the resistance offered to continuous currents, and unless a copper or other non-magnetic return is provided, this would constitute a very serious difficulty.

Mr. A. H. Robinson said—I should be glad if the author would kindly inform us the name of the book in which the Heyland diagram can be seen. Mr. Robinson

As regards variation in the shape of slots in the cores, I should think the variation was largely due to the cost of manufacture.

Has any allowance been made for balancing the rotor? There seems to be very little clearance, and as the bearing wears down, the rotor may come in contact with the stator.

The President, Mr. T. L. Miller, said—I am sure you will all agree with me that we are very much indebted to Dr. Marchant for coming here this evening and giving us this very excellent paper. Mr. Miller

Mr. Miller Apparently he has made things so clear that there is no necessity for many questions to be asked.

Mr. Kemp in his remarks referred to one point that struck me very forcibly in the reading of the paper, and that is, that in the more recent motors—the compensated and the repulsion motors—we are coming back to the commutator: that portion of the direct current motor which we have all been trying to avoid.

I do not think, however, that this commutator brings the same troubles in its train as it did some years ago, as I have a considerable number of direct current motors working in different parts of the country, where no trouble at all is experienced with the commutator.

Dr. Marchant has pointed out the great simplicity of the induction motor, and more particularly of that known as the "Squirrel-cage," which is, I think, the most simple type of motor that it is possible to obtain.

The trouble with the squirrel-cage motor, however, is that when you come to deal with motors running from public supply mains they can only be used up to the maximum of (say) 5 H.P., as when you go beyond this size the starting current becomes so great as to interfere with the regulation of the system. The other disadvantage of the induction motor, from the station engineer's point of view, is the lower power factor, which necessitates the use of larger mains and gives rise to greater ohmic losses than would be the case with a direct current motor.

In the question of speed regulation again, the induction motor is at a great disadvantage as compared with the direct current motor, as although speed regulation can be effected by inserting resistances in the rotor circuit, which, as Dr. Marchant has pointed out, is similar to the speed regulation of direct current motors by introducing resistances in series with the armature, it is, of course, a very wasteful method, and is only applicable where comparatively small range of speed regulation is required.

One of the best fields for induction motors is, perhaps, in connection with mining work and other situations where there is danger of an accumulation of explosive gases.

For such cases the squirrel-cage motor would appear to be admirably adapted, as it is quite impossible in many mines to use motors with commutators, on account of the danger of igniting the explosive gases present.

At the present time we are looking forward to the decision of the

Departmental committee which has been considering the question of the transmission of electricity in mines, when, no doubt, regulations bearing on this subject will be suggested. Mr. Miller

Dr. Marchant refers to the question of power factor in the case of induction motors, and points out that this requires further copper, but against this he puts a saving due to the smaller amount of copper required in transmitting a given power by the three-phase system as against that required when transmitting power by direct current system. It is hardly necessary to point out that with the three-phase system we have three conductors, and that these three conductors require insulating, and that although there may be a certain gain in the *weight* of copper used, when one comes to take into account the cost of insulating three conductors, as against two in the case of the direct current system, I do not think that the cost will be very much reduced. In addition to this, I think the question of saving of copper is really after all very much a question of pressure, and that if we worked the direct current system at the maximum pressure, instead of the square root of the mean square value, the saving in copper would, I think, disappear.

Professor MARCHANT, in reply, said—Referring to Mr. Kemp's remarks relative to brake horse power, the B.H.P. is very nearly proportional to the square of the voltage, independent of the frequency. The latter will perhaps slightly increase the power that you will get as the speed goes up, but the actual speed variation of the generators in large stations is negligible. Prof. Marchant

As to the cascade system of working, it is nothing but a series parallel arrangement, with the distinction that usually the paralleling ends when one motor is coupled direct to the mains.

Now as to compensators, the argument which has been made against the Heyland system is that you have to use a commutator, and that this means more trouble. But, as Mr. Miller has stated, the trouble of using a commutator is a thing of the past, however it means a greater expense in construction. That was a point made by Mr. Meyer in his paper last week.

The compensating device is a very beautiful thing in its way, but it is not of much use, except on machines of large power.

As to the troubles met with due to the throttling of current on the surface of iron conductor rails, that is a serious thing in alternating current work ; I was making a comparison more between single and three-phase systems. The trouble can be got over by using a return wire in place of the rail.

Prof. Marchant As to the Heyland diagram, an excellent book on this subject is Dr. Hayls' "Alternating Current Working."

Balancing of the rotor I have never heard of. The trouble in all motors is that you have to have very long bearings that will not wear appreciably after a considerable time of running. If they do wear, the rotor begins to knock directly on account of the small clearance.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

EIGHTH MEETING—10TH FEBRUARY, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I., Mech. E., M.I.E.E., PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. J. M. GIBBONS, J. PATTISON KEMP, F. W. LE TALL, and R. P. NASH, as *Members*; and Mr. E. D. NICHOLSON, as a *Student*.

LONG DISTANCE TRANSMISSION FROM HIGH HEAD WATER POWERS.

BY ERNEST KILBURN SCOTT, Assoc. M. Inst. C.E., M.I.E.E.

STRICTLY speaking, in an Electrical Transmission from Water Power there are two separate transmissions, the first being the hydraulic transmission from the service reservoir to the power house, and the second the electrical transmission by overhead wires (or possibly underground cables) from the power house to the consumer. It is mainly to these two aspects of the Transmission of Power problem that the author proposes to confine this paper. Further, as he wishes to draw members' special attention to the value of *high head* power, much of the information must necessarily deal with plants abroad, where such water powers are available.

References will be made from time to time to some multiphase transmissions of power with which the author has had personally some experience, namely, the Burma Ruby Mines, the Raub Gold

Mines, the Rezende Gold Mines (see Appendix A), and the Snowdon Transmission of Power for utilizing an 1,150 feet fall (see Appendix B). The author has thought it best to give these particulars as Appendices, as they are likely to be more useful for reference in that form.

THE TANGENTIAL WATER WHEEL.

The simplest of all the Prime Movers which are in use to-day, is undoubtedly the Pelton Wheel, or as it should more properly be called, the tangential water wheel. Although in the larger sizes it is closely associated with the development of electric transmission in the Western States of America, yet the idea of the wheel is very old. Indeed, Branca described it in 1629, and in 1767 Borda clearly enunciated its main principles when he wrote—"To produce its total "mechanical effects the water serving as its motive power must "be brought on to the wheel with impulse and quit it without "velocity."

In the modern wheel the water strikes the bucket and imparts impulse causing rotation, and the bucket is also so shaped that the direction of the jet is reversed almost back upon itself; and this reversed flow as it emerges being reactive tends to further increase the power and speed of rotation.

The reason why California became the home of the modern tangential wheel is simply due to the fact that *limited* quantities of water at *high* head constituted the only source of power available for working the mines and mills, &c. The old "hurdy gurdy wheel," built of wood throughout, was developed by the early Californian miners, and even in 1870 S. M. Knight, who was the first to bring out the cup-shaped metal bucket, was still making wooden wheels. In 1872 N. J. Coleman patented a wheel in which the buckets were double with a wedge between, very much like the present Pelton wheel, the *stream splitting and curving off to each side* with sufficient clearance to miss the next following bucket. Table No. I will give some idea of how quickly the modern tangential wheel has developed since its primitive days, single wheels of 1,000 horse power are quite common. Last year a wheel was installed at Butte Creek, California, which gives 3,700 horse power on a fall of 1,530 feet, the speed being 240 revolutions per minute. The revolving mass weighs 40 tons, and is carried on a hollow forged nickel steel shaft, the three-phase alternator being between two bearings, and the tangential wheel overhung.

TABLE I.

Particulars of Tangential Wheels in some Electric Power Stations.

Name of Power Company	Place	No. of Generators	Effective Head Feet	Output of Generator Kilowatts	Revolutions per Minute	Type of Wheel
Edison Electric Co., Grafton	California	4	300	750	300	58-inch
Pikes Peak Hydro. Electric Co. ...	Colorada Springs	3	2,100	750	450	--
Pikes Peak Power Co., Victor	Colorado	5	1,050	400	450	Dbl. Wheel
Clark Electric Co., Ophir	Utah	1	700 480	250	450	Dbl. Wheel
Northern Californian Power Co.	Volta	3 2	1,150	750 1,500	—	1,500 H.P. 3,000 H.P.
Butte County Electric Electric Power and Lighting Co. ...		2	590	—	300	58-inch
Guanagunto Power Co.	Mexico	—	320	1,500	200	—
Vancouver Power Co.	British Columbia	3	390	1,500	200	3,000 H.P.

NOTE.—For 1902 there were 1,390 water wheels at work in American electrical stations, aggregating 438,470 horse power, and eight per cent. of the wheels had a capacity of over 1,000 horse power each.

To show how much small differences in the shape of the bucket affect the efficiency, an experience at the San Joaquin Electric Co. at Fresno may be mentioned. The head is 1,410 feet and each wheel develops 500 H.P. When first erected the wheels were rather under power, so the original buckets were removed and another pattern (the ellipsoidal) substituted. With the same nozzle and same quantity of water the output was at once increased over ten per cent., as shown by the readings of the switchboard instruments.

As compared with the turbine, the first cost of the tangential wheel is very much less, and for high heads running into many hundreds of feet, it can be used where a turbine is impossible. At the same time its cost of maintenance is but a fraction of that of the turbine, for a complete set of new buckets cost very little and can be mounted very quickly by an unskilled man.

Regarding efficiency, any good make of wheel will give 80 per cent., and there is also this to be said, that it maintains its efficiency, whereas that of a turbine constantly decreases as the wheel wears away in its casing, thus allowing the water to pass *by* instead of *through* it.

A disadvantage of the turbine is that the variation in design is limited by reason of its excessive cost for large diameters, the tangential

wheel, on the other hand, permits of very wide and free scope. As a matter of fact, wheels have been made from 3 inches to 30 feet in diameter, and to work under heads varying from 35 to 2,530 feet, and for speeds varying from 65 to 1,150 revolutions per minute.

To show the ease with which the tangential wheel adjusts itself to circumstances, it may be mentioned that at the power house of the Clark Electric Co. (see Table I) there is only a limited supply of water. The generating unit is therefore constructed with two Pelton wheels, each working under a *different head* of water, the governing being effected by combination needles and deflecting nozzles actuated by Lombard governors.

VALUE OF HIGH FALLS.

The author would remind engineers at home that California is not the only country where there are *high head* water powers. In our various Colonies, to say nothing of the South American and the African Continents, and the far East, there is any amount of water power for which the tangential wheel is the most suitable prime mover. As a rule, travellers are only impressed by falls of moderate height over which the water comes tumbling in masses; they do not appreciate the fact that a mountain streamlet dropping 1,000 feet or so in a short horizontal distance may be capable of developing much more power at a fraction of the expense. A low fall is generally in the valley where the land has considerable value, and where, if the water is interfered with, there may be legal difficulties with landowners and occupiers. A mountain stream, on the other hand, generally runs through land of little value, or as the Ordnance map quaintly puts it in the case of Snowdon, "through *rock* plantations."

With low heads a variation of a few feet in the height of the storage reservoir or in the tail race makes quite an appreciable difference in the power, whereas on a high fall a few feet is immaterial. Again, owing to the smaller amount of water required for a given power quite a moderate storage allows of the actual power of the stream being multiplied several times wherever the maximum power is required for *only a part* of the 24 hours.

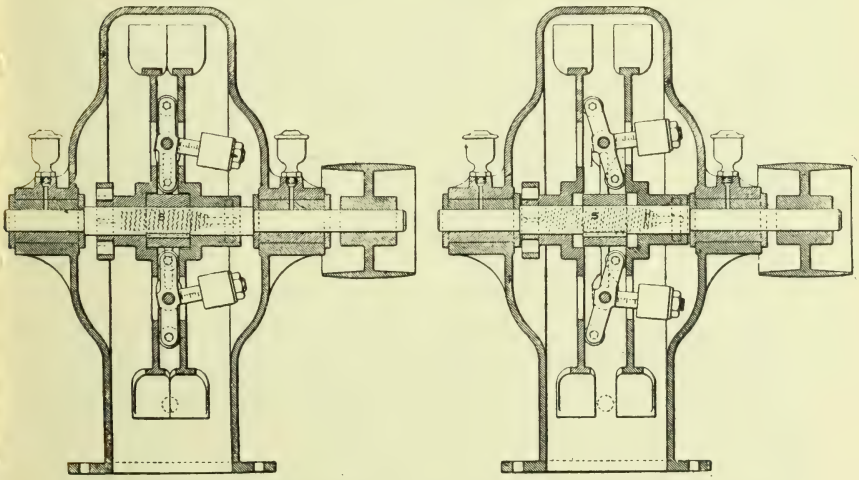
A glacial stream or mountain torrent is better for the purpose of power work than water of a lower altitude, because when the water passes into pipes at a point above the tree line there is so much less risk of trouble from organic matter. In the case of Lake Llydaw (see Appendix B), for example, there are no trees round the lake, and so far as can be seen, no weeds in the lake. A river, on the other hand,

may require expensive gratings, and strainers are necessary to catch driftwood, leaves, and other smaller floating obstructions, and gangs of men are kept constantly at work clearing such strainers.

TANGENTIAL WHEEL GOVERNORS.

The one tricky feature of a tangential or Pelton wheel is the governing device, for water under high head is somewhat difficult to control on account of the great pressure. Thus, at 1,150 feet head the static pressure is 500 pounds per square inch, and with a 27-inch diameter steel pipe $\frac{11}{16}$-inch thick, the bursting stress is nearly five tons per square inch, giving a factor of safety under normal pressure due to the head alone of about 5 to 1. Now the inertia of a column of water moving rapidly through a long pipe is so enormous that any attempt to shut off the water suddenly would be liable to burst the pipe. The *sensitive* governing of the tangential or Pelton wheel should therefore, where possible, be so arranged as to avoid shock to the pipe line.

There are three methods of sensitive governing under high heads. The *first* is by means of stand pipes, into which the flow of water is diverted when shut off from the wheel, relief valves being also provided. The *second*, which is used largely in the States, is to deflect the jet or stream away from the buckets, sudden changes of speed in the



BUCKETS CLOSED UP. BUCKETS SPREAD APART.

FIG. 1.

The Cassel Tangential Water Wheel.

centrifugal governor bringing a nozzle deflecting mechanism into action. The *third* is a method introduced by Mr. E. F. Cassel, in which the wheel is divided along the centre line of the buckets into two sections, and the centrifugal force developed in the rotation of the wheel body itself is arranged to cause the two sections to separate slightly. A portion of the water jet is thus allowed to pass between the buckets, instead of impinging directly against them, and being part of the wheel itself, the governing action is instantaneous. The governor gear is exceedingly simple and self-contained, with only four moving parts. (See Fig. 1.)

It will be seen that the Cassel wheel is a fundamental departure in the design of tangential wheels, in that the speed is kept constant owing to the method of construction of the wheel itself, and is not in any way dependent upon the control or variation of the volume of water flowing at any time. This characteristic is of great value for power transmission, for whatever the variation in load, or volume of water passing through the nozzle, or whatever the variation in pressure of head, the wheel cannot race. In a particular test a pressure of 40 pounds per square inch at the nozzle gave 450 revolutions per minute. On the pressure being increased gradually from 40 pounds to 400 pounds the tachometer showed no appreciable variation, whilst on the pressure being increased or decreased suddenly the momentary variation fell to normal in five to ten seconds.

Of course, in the above, the author has been considering governing for sudden changes of load. Where the load is reduced or increased slowly, then the water can be turned off or on, without danger, either by hand or by an additional governing device. This adjustment of the water supply is usually effected by a needle in the nozzle, and is subsidiary to the above described *sensitive* governing. Where the water must be carefully conserved then only throttling is possible.

CONSTRUCTION OF STEEL PIPES.

Rivetted pipes have the objection that the rivets and joints cause eddies and so loss of head, especially at the high velocities employed for Pelton wheel work. They are also more liable to corrosion, because the preservative coating may become worn or knocked off the rivet heads, &c.

There is also the further disadvantage that on account of these rivets reducing the strength of the pipe some 30 or 40 per cent., the pipes have to be just about that much heavier, and not only must this

extra material be paid for, but the cost of freight and erection is increased. In an out of the way situation, on a mountain side, this

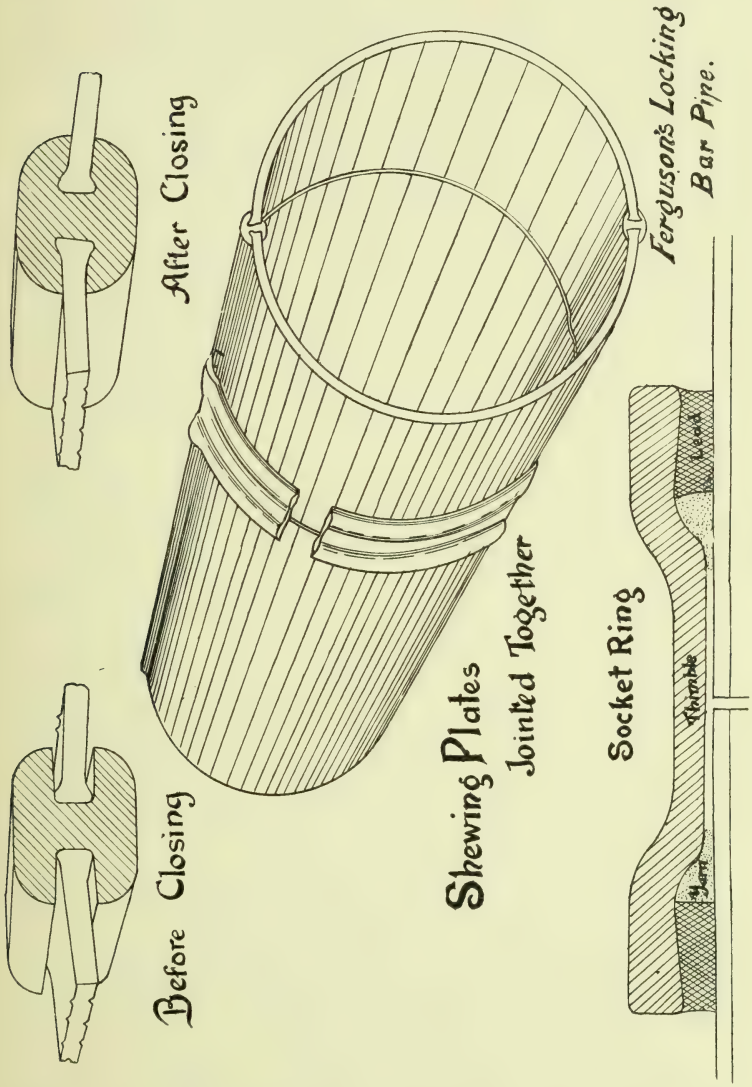


FIG 2.

latter is a very important matter. A further disadvantage is the necessity for frequently caulking the joints, and possible replacement of rivets.

For very large pipes rivetting must be used, unless the conduit is made of armoured concrete, as in the 10 feet tube of the Fure and Morge Power Station in France.

The alternative methods of constructing a steel pipe are either by lap-welding or by the Ferguson locking-bar system. The lap-weld is well known, and, if carried out by a good firm, makes an excellent job; it is somewhat expensive.

In the Ferguson locking-bar pipe shown in Fig. 2, it will be seen that each pipe consists of two plates, the edges of which are up-set in a special machine. The plates are then bent into semi-circles, and the steel locking-bars are squeezed down cold by hydraulic pressure. The Ferguson pipe has the same advantages as a welded pipe, that is to say, there is a minimum of friction owing to the absence of rivets and joints, and at the same time it has the advantage over welded pipes that all the material is made up cold so there is no fear of defects due to burns and incomplete welds. As there are no exposed plate edges, no caulking is necessary, owing to the special system of manufacture.

The Ferguson pipe can be made of considerable length, thus requiring also fewer joints, and consequently reducing the cost of laying. On the Coolgardie line * the pipes were 28 feet long and 30 inches in diameter, and they were turned out at the rate of about 15 minutes for each length. The pipes were also manufactured on the site of pipe track, thus giving great saving in carriage and freight.

The highest heads in use are: 2,530 feet at an Installation near Seattle, Washington, 2,250 feet at the Paunco Mines, Mexico, and 2,100 feet at Pikes Peak Hydro. Electric Company at Colorado Springs. The difficulties which have been surmounted in carrying out these installations may be gathered from the fact that the pressure at the bottom of the pipe line due to a 2,250 feet static head of water is about 900 pounds per square inch.

Although it may be possible to have a single pipe line for a high pressure installation, it is better to employ two mains, as it is then possible to drain and paint one internally during the slack season, without suspending the supply of power; they can also be braced together and so form a pipe-line which is particularly strong against lateral displacement.

* The Coolgardie line, over 200 miles long, is the largest pipe contract as ever undertaken. After thorough investigation by Prof. Unwin and Messrs. Carruthers & Deacon, the contract was awarded to Mr. Mepham Ferguson, an Australian engineer. He has recently established works at Tipton, and is making the pipes for the Mond gas transmission.

In connection with growths in the pipe, it may be mentioned that there is less likelihood of it in welded or a Ferguson pipe than there is in a rivetted pipe because there are fewer obstructions.

These growths appear to be caused by water running over peaty land, so that when the water is taken from a mountain stream, at a considerable altitude, it is more likely to be pure, and there is not so much chance of growths being started. The high velocity in a power pipe-line is also against its forming. In any case it is well to provide for large scouring branches, so that the pipes may be cleaned occasionally.

The top end of a pipe-line has, of course, only to carry a few pounds per square inch, but it is not advisable to reduce the thickness of the pipe below a $\frac{1}{4}$-inch whatever its diameter, and to allow for corrosion, &c., it should be $\frac{5}{16}$-th. Where the pressure begins to be considerable, a factor of safety of five should be allowed, one for corrosion and four for reserve.

Pipes made in this country are usually preserved by being dipped in hot Angus Smith's solution. In America, Assyrian rubber coating and carbonising coating are much used. Siderosthen, a black varnish paint, is useful for painting on when the pipe is *in situ*.

Where the top end of the pipe enters the lake or surface reservoir, it is necessary that the water should be drawn from a point 30 feet or so below normal level. If this means a considerable amount of tunnelling or excavation, a syphon may be employed, the main being charged by an ejector fixed at a point some 50 feet or so below the normal water level. Whilst this syphon method is quite a feasible proposition the better plan is of course to lay the pipe line so that the water runs directly into it by gravity.

The record for pipe lines of large diameter is held by the Ontario Power Co., who bring the water across Victoria Park, Niagara, in steel pipes 18 feet in diameter. At the Staines reservoir Messrs. Piggott & Co. have supplied pipes, 6 feet 4 inches diameter, work at a pressure of 40 pounds per square inch, which are overlaid, joints and all, with a 6-inch thickness of concrete so that the pipe is practically a concrete tube having a rivetted steel lining. A 10 feet diameter conduit of the Hydro Electric Co., at Fure and Morge in France, is made of armoured concrete.

EXPANSION OF STEEL PIPE LINES.

One of the problems in connection with laying down steel pipe lines for power purposes is the question of expansion. For example,

with a difference of temperature of 100 degrees Fahrenheit, a steel pipe 100 feet long will lengthen $\frac{3}{4}$-inch, which means that a straight pipe a mile long will extend over three feet. Fortunately, when working under ordinary conditions with the pipe full of water, the difference of temperature is not likely to be anything like so much as 100 degrees Fahrenheit, especially if the water is taken from a lake or mountain stream. Again, pipe lines are usually laid in a trench in the ground and covered with turfs, leaving only the joints exposed. Besides acting as an insulation this has the advantage that the pipes are not so objectionable a feature in the landscape. In the case of the Coolgardie pipe line, which, it may be mentioned, is over 200 miles long, an ingenious method of keeping down the temperature is by periodically whitewashing the upper surface of the pipe. This method, of course, can only be adopted where appearance need not be considered, and in any case it is scarcely called for, except in tropical countries.

In some of their pipe contracts Messrs. Piggott & Co., of Birmingham, have used flanged pipes, and take up the expansion by inserting at intervals a short piece of corrugated pipe. The corrugations are liable to increase the water friction, but this can be obviated by inserting a thin steel liner inside the pipe.

A method of taking care of the expansion is by socket or Kimberley joints sealed with lead, each pipe length then takes up its own expansion, and the joints can be caulked or re-made easily. These joints also enable the pipe to follow slight inequalities of the ground.

To ensure efficiency with lead joints, it is essential that the pipes be laid straight from point to point, and where sharp bends must be made, the points where the angles occur should consist of strong junction boxes secured on rigid foundations. Between these boxes the pipes act as columns in compression, and such columns being in unstable equilibrium the pipe must be held in line by foundations and clamps at frequent intervals. In this way the end pressures are received entirely by the junction boxes, and the transverse pressures by the pipe supports.

Large radius bends have lower frictional loss, but in any case the loss of a few feet head in several hundred feet is quite unimportant. For low falls of (say) 50 feet or so, 2 or 3 feet loss is a large percentage, and in such circumstances large radius bends must be used. The shorter length of pipe involved generally enables them to be put in without much expense.

OVERHEAD ELECTRIC TRANSMISSION LINES.

The experience in the States regarding route of high tension pole lines is that "Private Rights of Way" are preferable to running the wire alongside the highway. The wires can then be laid in a bee line from point to point, whereas if they follow the highway there may be frequent turns requiring poles closer together and extra guys and insulators, &c. There is always the question, also, of the authorities giving trouble as to limitation of voltage, and the widening and paving of roads, &c.

The Niagara to Buffalo line runs for nearly 25 miles on a private right of way 30 feet wide. The 80 miles transmission from Rochester to Pelham, N.H. (13,200 volts); the 65 miles from Canon Ferry to Butte (50,000 volts); and the Colgate to Oakland 142 miles transmission (40,000 volts) are mostly run on private rights of way, varying from 50 to several hundred feet wide.

In many of the long distance transmissions in America it has been considered advisable to have two independent pole lines, with a single circuit on each. In this way an arc started on one circuit cannot communicate with the other, and there is at the same time greater ease and safety in making repairs. The lines are usually run together some 40 yards or so apart, but on the Welland Canal system the two lines are located several miles apart, and are respectively 35 and 37 miles long. On the Cauvery Falls Transmission there are two parallel lines of poles 60 feet apart, the distance from pole to pole being 130 feet. When transmission lines are in duplicate, the capacity of each one should be sufficient to transmit the full power at increased potential in case of emergency.

CONTINUITY OF ELECTRIC SUPPLY.

A point in connection with overhead transmission lines is the question of continuity of supply. One reply to objections on this score is the fact that abroad there are hundreds of towns supplied from overhead transmission lines, and the author has yet to learn that citizens in such towns abroad are less particular as to what they consider their rights than citizens in similar communities in this country. The fact of the matter is, it would not pay any power company to give a discontinuous supply, as if so, they would soon find themselves in financial difficulties. If, therefore, we find that the

shares of the large power companies in North Italy,* and other parts of the Continent, are at a substantial premium, and that many power companies in the States are also doing so well, it is only fair to assume that these companies are *carrying out their obligations* properly.

The case of the Cauvery Falls (see Table II) may be specially instanced. The Mysore Government laid down a 5,000 H.P. power station, and 92 miles (30,000 volts) transmission line at a cost of about £340,000. It has now been running two years, day and night without a break, and already the whole of the power is taken up by ten of the Gold Mine Companies at Kolar. It is estimated that the Mysore Government will recoup practically the whole capital outlay by the end of the 6½ years, and at the same time the mines will save well over half a million sterling in working expenses.

In case a fault does occur on an overhead line, it is much easier to find, and very much easier to repair than if it were underground. Some of the transmission lines abroad have several hundred miles of wire, and yet by means of mounted men the whole system can be inspected in an hour or so, and the bare telephone wires enable them to communicate with power house or sub-stations at once. If such cables were underground it might take days to locate the fault and repair it, and many more men would be required, as there would be trenching to do, whilst the joint itself would take longer to execute.

LIMITATION OF VOLTAGE.

The limitation of voltage on an overhead transmission line is governed by the insulation strength of the insulator and the losses through the air between the conductors.

Regarding the insulator, it is really only a matter of having a good dielectric material to resist puncture, and suitable dimensions to a well thought out design. When insulators were not so well made as they are now, they constituted the limiting factor, but the manufacture

* The Edison Electric Co., who laid down the Paderno Station to give 15,000 horse power at 14,500 volts, and transmit current 19 miles to Milan pays 15 per cent., the shares issued at 150 now standing at 590. The Lombardy Electric Co. distributes about 20,000 horse power at 16,500 volts, to many towns and villages, silk and cotton mills, &c., throughout Lombardy, pays 7 per cent., and the shares issued at 500 now stand at 930. In both cases a large percentage is allowed for depreciation, and as the whole of the power is already taken up, both companies are laying down large extension power stations.

TABLE II

Particulars of some Long Distance Transmission Lines.

Name	Distance of Transmission.	Voltage	Number of Pole Lines	Size of Wire in circular Millimetres	Material of Wire	Distance apart of Poles	Material of Poles	Length of Pole
	Miles					Feet		Feet
Niagara and Buffalo ...	20 & 23	22,000	Two	12—350,000 6—300,000	Copper Aluminium	75 112	—	—
Canon Ferry and Butte ...	65	50,000	Two	3—106,500	Copper	110	Cedar	35 to 90
Rochester and Pelham ...	80	13,200	One	—	Copper	100	Chestnut	35
Shawnigan Falls to Montreal	85	55,000	One	3 conductors each 7 strands of No. 6 B&S	Aluminium	100	Cedar	35
The Cauvery Falls, India...	92	30,000	Two	No. O, B & S Gauge	Copper	130	Composite Poles, Jarrah, Iron and Steel	30 (17 of wood and 13 of steel)
Electra and San Francisco	154	60,000	One	3—471,034	Aluminium	—	Squared Redwood	—
Colgate and Oakland ...	142	40,000	Two	3—133,225 3—211,600	Copper Aluminium	132	—	25 to 60

has been so perfected, that in an ordinary dry and pure atmosphere, such as in the States, insulators will easily carry 60,000 volts without appreciable leakage.

The loss between wires is a more important matter, because beyond a certain voltage the leakage increases very quickly. For example, experiments carried out by Mr. Mershon show that with a frequency of 60 and wires 52 inches apart, the loss in a certain test circuit was about as follows :—

60	Watts at	...	30,000	Volts.
80	"	...	40,000	"
140	"	...	50,000	"
750	"	...	55,000	"
1,750	"	...	58,000	"
3,000	"	...	59,000	"

It will be seen that the leakage from wire to wire for a given distance apart increases very rapidly when the voltage exceeds a certain value.

The following are the minimum distances apart of wires for given voltages, but to cover contingencies the distances would be about doubled in practice :—

30,000	Volts	...	15	Inches	apart
40,000	"	...	22	"	"
45,000	"	...	35	"	"
50,000	"	...	52	"	"

In a dry climate where the transmission lines are seldom in fogs or clouds and the rain is not charged with sooty particles, the loss between wires is naturally much lower than will be the case near cities where there are impurities in the moisture of the atmosphere.

For any given conditions there is a certain economical voltage, because, whilst an increased voltage, with a given line wire, will reduce the loss in the wire, by decreasing the transmission current ; it will at the same time also increase the loss *between* the wires.

Wave form is very important, and the sine wave is undoubtedly the best. A flat wave gives less loss, but is not so stable. With an ordinary good wave form, and in a climate where the air and precipitated moisture are practically pure, 60,000 volts comes well within the limit for pressure.

The record of high voltage transmission is at present 60,000 volts on the Electra and San Francisco line, but 120,000 volts has been

temporarily employed for a lecture demonstration, Table III gives particulars of some three-phase transmissions which are now working or being erected in Europe, and it will be noticed that there are several above 30,000 volts. An interesting and significant point about this table is that it represents the activities of but *one* of the Continental firms, namely, Brown, Boverie & Co.

A 60,000 volt line is about to be laid down from Niagara to Toronto, and current for this will be supplied by the Canadian Niagara Power Company, who are installing five 10,000 horse power, 11,000 volt generators.* The three-phase current will be stepped up to 60,000 volts and transmitted 90 miles to Toronto by means of aluminium wires. In this country, with its fog and smoke, probably 20,000 volts would be about the limit, and the comparatively short distances do not call for more.

HIGH-TENSION INSULATORS.

The requisites of an insulator for high-voltage work are :—

(1) That its dielectic strength shall be sufficient to prevent the current passing directly through the material.

(2) That its dimensions and surface area shall be sufficient to prevent the passage of current over the outside of the insulator to its support.

(3) That the resistance of both the material and its surface shall be sufficiently high to prevent undue loss of energy.

(4) That it shall be mechanically strong enough to withstand severe stresses in time of bad weather.

(5) That it shall not be subject to deterioration whilst in service, particularly from heat and cold.

(6) That it shall not be so obstrusive as to form a target for the catapult or shot gun.

It was first thought that insulators with cups containing oil would be necessary for reducing the surface leakage, and insulators of this kind were used in the Frankfort-Lauffen 100-mile transmission at 30,000 volts. It has since been found, however, that the ordinary glazed surface is ample insulation. The principal duty of an insulator is, to prevent the current passing over the outside surface and *jumping* to the pin or cross-arm, a matter which oil cannot prevent.

*As a matter of interest it may be mentioned that all these machines as well as the last five units in the Power House No. 2 of the associated Company on the American side have internal revolving fields and external stationary armatures. It may be remembered that the earlier machines had the field poles external to the armature.

TABLE III.—THREE-PHASE TRANSMISSION OF POWER PLANTS

Name of Installation	Paderno, Italy.	Kander, Switzerland.	Briançon, France.	Ovesca, Italy.
Distance in kilometres	32	50	13	35
Number of generating units installed	7	5	3	2
Number of generating units to complete installation	7	5	—	3
Horse power of each generating unit.	2,200	900	2,200	1,500
Number of revolutions per minute ...	180	300	315 180	417
Frequency	42	40	42	41·7
Voltage on Generators	14,500	4,000	13,000	12,000
Voltage on transmission line ...	14,500	16,000	13,000	12,000
Whether transformer is single phase or three-phase	—	1	—	—
Output in kilowatts of step down transformer	—	300	—	—

Name of Installation	Saragozza Télédyanamica, Spain.	Collins, Italy.	Marzotto-Valdagno, Italy.	Redaelli-Lecco., Italy.
Distance in kilometres	80	90	—	6
Number of generating units installed	4	4	1	2
Number of generating units to complete installation	5	6	2	4
Horse power of each generating unit.	1,000	2,600	315	125
Number of revolutions per minute ...	500	315	570	375
Frequency	50	42	38	50
Voltage on Generators	3,000	4,800	3,000	500
Voltage on transmission line ...	30,000	36,000	16,000	10,000
Whether transformer is single phase or three-phase	3	1	3	3
Output in kilowatts of step down transformer	850	1,000	260	105

AID DOWN BY MESSRS. BROWN, BOVERIE & CO.

Lecco, Italy.	Fure et Morge, France.	Wild and Abegg, Italy.	Beznau, Switzerland.	Cômes, Italy.	Tosi-Novara, Italy.	Saragozza-Gallego, Spain.
21	50	—	80	37	—	45
3	5	1	9	5	1	3
3	6	1	11	5	2	5
550	1,350	880	1,000	650	700	1,500
400	300	230	66·6	420	125	300
40	50	46	50	42	50	50
3,300	3,000	10,000	8,000	4,000	10,000	3,000
16,000	26,000	10,000	26,000	20,000	10,000	30,000
3·1	3	—	3	3	—	3
650 400	1,150	—	1,000	630	—	1,375

Festi Rasini Giovanni Lup., Italy.	Castellanza, Italy.	La Romanche, France.	Crespi-Nembro, Italy.	Ovesca, Itaiy.	Agricultural Society of Lombardy, Italy.
6	—	35	30	—	22
2	2	3	3	1	2
4	4	3	3	—	—
810	2,700	2,500	1,000	1,800	140
64	107	375	500	417	250
42	50	50	50	41·7	42
10,000	11,000	4,350	4,000	12,000	500
10,000	11,000	33,000	40,000	12,000	16,000
—	—	3	3	—	3
—	—	2,500	900	—	130

In the case of many oil insulators supplied to tropical countries it was found that various kinds of insects soon ate up all the oil which was not dried up by the sun.

Although glass insulators have been much used in the States, they do not appear to have any advantage over vitrified porcelain in the matter of mechanical strength or resistance to piercing. On account of its transparency glass has, however, the advantage over porcelain in that it does not need an electrical test to pick out a good insulator, whereas porcelain must be carefully tested. Glass insulators are also lighter and less likely to be shot at than porcelain, for when the latter are white they offer a very tempting mark.

Glaze has no insulating value in itself, but is useful for preventing dirt sticking to the insulator. It will be seen that porcelain, which presents a very smooth surface, may contain internal cracks or cavities, or bits of pebbles, or the material may be very absorbent. For extra high voltages, therefore, it is well that they should be carefully inspected during the process of manufacture, and before the glaze is applied, and this is especially desirable with insulators built up of several parts and cemented together by glaze or other material. In the more complex forms porcelain insulators are distinctly cheaper than glass.

A form of insulator which is much used, the composite, consists of porcelain and glass, the porcelain underneath on the insulator pin, and the glass having a wide petticoat cemented to the top of the porcelain.

The best porcelain insulators have a polished fracture when they are broken, and they should be absolutely non-absorbent. The test for this is to place the pieces in a dry stove, weigh them, then immerse in water and weigh again. The weight should be the same in both cases. The test for puncture is made by setting the insulator in salt water and slowly increasing the potential until it is double the working pressure. In case of a composite insulator each portion must be dealt with separately and the potential should be kept on for one minute. It is interesting to note that insulators will withstand a much higher potential applied instantaneously than they will if applied continuously.

The wet weather test is made by causing a jet of water from a sprinkler nozzle, under pressure of 50 pounds, to play on to the insulator at an angle of about 30 degrees from the horizontal. Under these conditions the insulator should not arc over from the wire to the pin at a less potential than that which will exist in service between any two conductors.

As regards mechanical strength, the insulator should be able to withstand a side stress of at least ten times the pressure exerted by wind pressure on the conductor when the wind is travelling at 100 miles an hour. This mechanical test is particularly desirable for built up composite insulators, in order to be quite certain that the parts will not separate. With such insulators it is also desirable to test them in tension along the axis of the pin, for when transmission lines pass over depressions in the ground there is sometimes an upward pull on the insulator.

It may be mentioned that the greatest mechanical stress which the insulators have to bear is as a rule where the transmission line is spiralled. It is important to have extra strong insulators in such positions.

Under-hung insulators have been tried, but not with much success. The top of the insulator is supported by an inverted cup bolted to the under side of the cross-arm, and from the bottom of the insulator a pin extends which holds the wire several inches below the porcelain. The object is to place the wire below the cross-arm so that any snow which might pile up on the cross-arm will not come near the insulator. The wire, moreover, instead of being supported upon the top of the insulator, where it is connected with an extended wet surface, is supported from the part of the insulator which is most protected and the driest.

It may be mentioned that when working at high pressures and with ordinary insulators, the part around and near the live wire does not retain deposits of moisture or frost, but remains dry, the particles being repelled.

In any case when working, the small amount of power necessary to keep the surfaces dry is insignificant. Of course in starting up a "cold" line there is danger of breakdown if current is put on suddenly at full value, it should always be raised gradually.

The following are the dimensions of some high tension insulators which have proved very satisfactory in actual working.

Dimensions of Insulators for High Tension Lines.

Name of Insulation	Pressure	Material	Height	Outside Diameter
Provo	40,000 Volts	Glass	$5\frac{1}{2}$	7
Colorado	20,000 "	Glass	$5\frac{1}{2}$	$5\frac{1}{2}$
Colgate and Oakland ...	50,000 "	Porcelain	$11\frac{1}{4}$	11
Santo Ana to Los Angelos	33,000 "	Porcelain	$13\frac{1}{2}$	$6\frac{3}{4}$

Some of the insulators are fitted with porcelain sleeves round the pin, as shown in Fig. 3, and in order that water shall be shed from the petticoat in such a position as not to fall on the cross-arm or wire

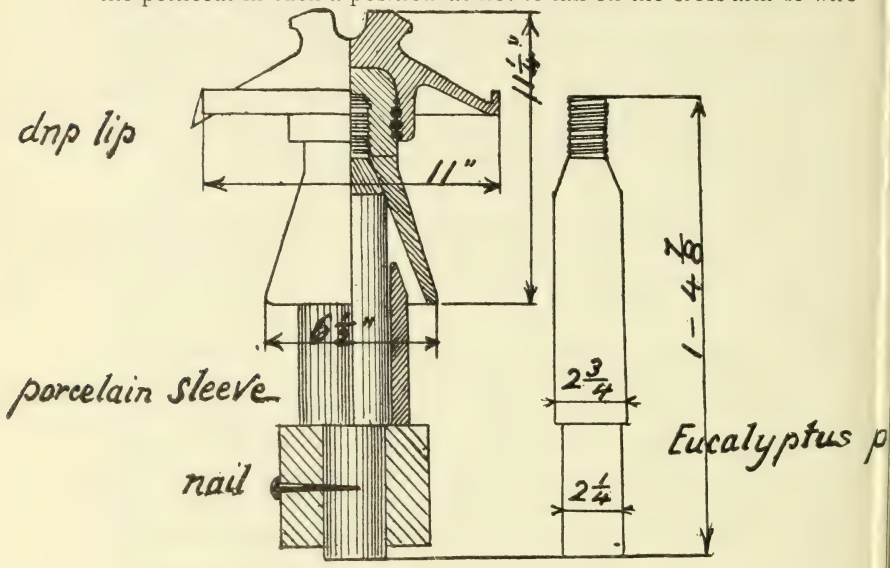


FIG. 3.
Insulator by W. J. Locke for 50,000 Volts, with Wooden Pin and Porcelain Sleeve.

conductor, it is fitted with a gutter and drip lip. On the 33,000 volt eighty-three mile transmission from Santa Ana to Los Angelos, iron pins are used having porcelain sleeves as shown in Figure 4.

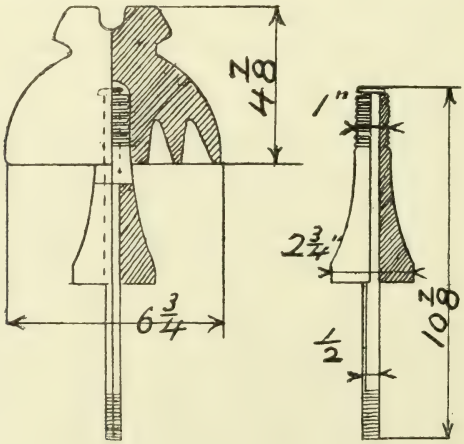


FIG. 4.
Insulator with Iron Stalk protected by separate Porcelain Sleeve, as used on the Los Angelos 33,000 Volt Transmission.

POLES.

Wooden poles are used almost exclusively for overhead transmission lines. The kind of wood depends on the country or district, but fir, spruce and pine are commonly employed, whilst in the States harder woods, such as chestnut, cedar, and sawn redwood are also used. A good creosoted fir pole will last 30 years. In the Raub plant (see Appendix A) a local cedar wood was employed, the butts being charred and tarred.

White ants and other insects are a great nuisance in tropical countries, and jodelite is said to be a preventative against them. Asphaltum is also used. It was mainly on account of the white ants that on the Cauvery Falls Line a composite pole was used consisting of 17 feet of 7-inch Australian jarrah in a steel socket 13 feet long. The steel is buried 6 feet in the ground, so that the pole projects 24 feet, the minimum height of wires above ground being about 20 feet. A layer of concrete inside the steel tube prevents the ants climbing up inside.

In many cases it is possible to find the timber on the ground. This was the case in the Burma Ruby and the Raub Gold Mines which are mentioned in Appendix A; but for the Rezende Gold Mines in Rhodesia steel poles had to be sent out. For the purpose of easy transhipment the parts telescoped together. The transmission line for the Government Cordite Factory in Southern India has steel poles.

A curious accident occurred on the San Bernardino and Pomona Line, 30 miles at 15,000 volts, two of the wooden poles being set alight by a defect in the insulators. The poles burned to the ground, leaving the line hanging clear without anyone at the generating station or sub-station being aware of the fact.

For transmission circuits it is far more important to have poles very strong rather than very long. For one thing short poles offer less surface to the wind, and the stress on struts and guy ropes is smaller.

Mr. Alton D. Adams gives it as his opinion that:—"No poles "should be used with a top less than 7 inches in diameter, and a "pole with this top should not be required to carry more than three "No. 2 wires. A pole with 7 or 8-inch top and 30 feet "long should measure not less than 12 inches in diameter at the "butt. For longer poles the diameters at the butt should increase "up to at least 18 inches for a round pole 60 feet long."

On the line between Electra and San Francisco (see Table II)

square-sawed redwood poles are used, having the following dimensions :—

Height Feet	Top Inches	Butt Inches	Depth in ground Feet
35	7 × 7	12 × 12	5·5
40	8 × 8	13½ × 13½	6
45	9 × 9	15 × 15	6·5
50	10 × 10	16 × 16	7
60	11 × 11	17 × 17	8

It may be mentioned that the reason for the varying length of poles is because in going over depressions in the ground the longer poles enable the wire to be kept at approximately the same level.

Where the soil is soft or the poles have to resist heavy strains, the stability may be much increased by making the hole two feet larger in diameter than the butt, and partly filling in with concrete. In good ground the hole is made as small in diameter as possible.

Where there are curves or changes in the direction of the line, the poles must be guyed or braced, and on long straight stretches it is usual to guy or brace every fifth pole in the direction of the line, to prevent them falling back in case the line wire is cut or broken.

As ordinary traction type strain insulators cannot be relied on with lines that operate at very high voltages, the strain insulator guys are made of timber 4 by 6 inches in section, and 10 to 20 feet long, with the guy-rope fastened to each end. This does not make a particularly good job, and on the 60,000 volts transmission line between Electra and San Francisco, the use of guys has been mostly avoided and wooden struts employed instead.

It may possibly be of interest to give some prices of wooden poles as supplied by English firms.

TABLE IV.

Length	Diameter at top of Pole	Diameter 5 Feet from Butt	Price Creosoted
32 feet	6¾ to 8½ inches	10¼ inches	17s. 2d.
30 "	6½ to 8¼ "	10 "	15s. 0d.
28 "	6½ to 8¼ "	9¾ "	13s. 8d.
26 "	6½ to 8¼ "	9½ "	12s. 10d.

CROSS ARMS.

Wooden cross-arms are the weakest part of the overhead equipment, as they are so liable to be "wind shaken" or "weather cracked," and so allow moisture and dirt to settle in the cracks, and form a path of low resistance. To prevent it the cross-arms should be specially treated to fill all cracks and fissures, and well crowned to allow water and snow to fall off easily.

In this country cross-arms are usually made of oak, in the States they are of yellow pine, treated with asphaltum or linseed oil.

A gain or notch is cut in the pole to receive the cross-arm, and it is held by one $\frac{3}{4}$ or $\frac{7}{8}$-inch bolt. If longer than 5 feet it is further secured by braces underneath. For example: on the Canon Ferry to Butte line at 50,000 volts each brace is of maple wood 3 feet long and 3 inches square, the cross-arm is 8 feet long, the insulators being $7\frac{1}{2}$ feet apart. The whole is fastened with wooden pegs as metal work is barred for such high voltages.

On the Cauvery Falls line three (No. O. B. and S. gauge) copper wires form an equilateral triangle, one insulator being carried on the top of the poles and the two lower ones by a cross-arm of jarrah wood.

On the *first* Niagara Falls to Buffalo line there are two yellow pine cross-arms per pole, these cross-arms being 2 feet apart, 12 feet long, and 4 inches by 6 inches in section. This pole line carries 12 copper wires. On the later pole line for this same transmission each pole has two cross-arms, the upper carrying four and the lower cross-arm two wires, so that one three-wire circuit is strung on each side of the poles, the two wires on the upper and one on the lower forming an equilaterial triangle.

One of the early Californian transmission lines, which ran for several miles within a few hundred yards of the sea coast, was found to have the cross-arms partly burnt, although the pressure was only 10,000 volts. The burning appeared as a blackening between the insulators on that side of the arm toward which the winds came from the sea. They were green, but since they have been replaced by dried and specially treated cross-arms the charring has ceased.

PINS FOR INSULATORS.

It is common practice in the States to mount extra high tens on insulators on wooden pins (see Fig. 3) made of eucalyptus, oak, or locust wood, treated with linseed oil, hot asphaltum, or paraffin.

The idea is that wooden pins raise the installation of the pole system as a whole, but it is doubtful.

Troubles have arisen on some lines by sparks passing from the outer edge of the insulator and making small holes in the pin, so that in time it becomes charred. This burning of the pins generally occurs where the porcelain insulators were too small, or the outside glaze imperfect.

Iron pins are better than wood, because, in the first place, to secure sufficient strength in the shank, a wooden pin must be of such a large diameter that the size of the cross-arm is considerably increased. Again, where there is a tendency for the line wire to raise or pull the pin out of the cross-arm, as for example, when crossing depressions in the ground, the usual nail driven through the cross-arm into the shank of the pin is not strong enough. With an iron pin, on the other hand, a thoroughly firm job can be made.

The insulator pin of the Vancouver Power Company consists of a steel bolt, 12 inches long, with a cast-iron sleeve, $4\frac{1}{4}$ inches long, fitting tightly in the cross-arm. The thread of the pin is made of lead, cast upon the end of the steel bolt, which is first ragged, to hold it firmly. The idea of the lead is that the insulator shall not grind against an unresisting steel pin, and so be broken, this being one of the principal reasons why wooden pins have been so much used.

CROSSING WIDE ESTUARIES OR RIVERS.

It sometimes happens that a wide estuary or river has to be crossed by a transmission line, and in such a case three methods are available :—

(*a*) The overhead line may be continued as a single span between high towers on each bank, or it may cross in several spans, piers being built for the purpose in the water.

(*b*) The overhead line may connect to a submarine cable, the insulation of which will be exposed to the full voltage of the transmission.

(*c*) A submarine cable may be laid down for a moderate voltage, and connected at each bank with step down and step up transformers.

The first method has been adopted for the transmission line between Colgate and Oakland, where it crosses the Carquinez Straits by a span of 4,427 feet, the voltage being 40,000. In order to allow ships with the tallest masts to pass under, it was necessary for the lowest part of the conductor to be at least 200 feet above water level. Two steel towers have been built 4,427 feet apart, and

between these four galvanised steel wire cables are suspended, each having 19 strands, and measuring $\frac{7}{8}$-inch diameter. The breaking strain of each cable is 44 tons, and the electrical conductivity is equal to No. 2 gauge copper wire. The cables pass over steel rollers on the towers, each cable being secured by a series of strain insulators, the total pull of about 12 tons being taken by an anchor.

On the Vancouver transmission line there is a somewhat similar case over the Burrard inlet, the span being 2,800 feet. At one side there is a steel tower 140 feet high, the other side being sufficiently high so as not to require a tower. Three galvanised plough steel cables, with wire centres and $\frac{9}{16}$-inch over all diameter, are employed for carrying the current across.

When crossing a stream or river the wires are spread out horizontally instead of forming the usual equilateral triangle. On the Cauvery Falls line there is a span of 525 feet and the wires are spaced 10 feet apart. They are carried on special pole structures of framed wood supported on a triple masonry foundation, and guyed back to the ground by steel cables. For crossing this span the hard drawn copper wire is replaced by silicon bronze, and it may also be mentioned that this material is used when crossing over railways. It is much used on Indian Government telegraph lines.

The second method has been adopted on a transmission line between Portsmouth and Dover, N.M., where an arm of the sea is crossed by a three-phase submarine cable 4,810 feet long working at 13,500 volts.

Of course if a few miles more of overhead transmission line will enable the line to be carried further up stream, so as to enable the current to be carried across by an overhead span, it may pay to so deviate the line. For such high voltages as 40,000 or 50,000 an overhead line must be used in any case, for the lasting qualities of cable insulation at such pressures is as yet an unknown quantity.

LIMITATIONS TO SIZE OF WIRE.

The size of the wire is limited between 0·4 of an inch diameter as the largest size, and about 0·1 of an inch diameter as the smallest. This is due to the fact that it is extremely difficult to stretch a wire larger than 0·4 inch, and on the other hand it is not mechanically practicable to use wires much smaller than 0·1 inch because of their having to withstand wind pressure, snow and sleet. For small powers it frequently happens that a larger wire has to be used than is really

necessary,* and this is specially the case for the branch wires at the end of a transmission line. There are two ways of meeting this, one is to reduce the voltage so that a larger section is required, and the other is to use a lower conductivity material such as iron or aluminium. On the Telluride Power Transmission from Provo to Mercur mills, voltage 40,000, an iron wire is used on a branch line for transmitting 100 H.P. at 40,000 volts, a distance of three miles.

It may be noted that if only a few hundred kilowatts are transmitted through a line built for (say) 1,000 kilowatts, the cost per kilowatt will be high, and this shows how important it is that a transmission line should be worked up to its *full* output.

ALUMINIUM CONDUCTORS.

Probably the first important example of aluminium being used for transmitting electricity any distance was between the Power Station and the Pittsburg Company's Reduction Works at Niagara Falls. In this case the conductors were very large, being $\frac{3}{4}$-inches in diameter. The installation was eminently successful, and now instead of being an exception, aluminium transmission wires are very frequently used. Table V below gives the relative figures for copper and aluminium, and it will be seen that aluminium comes out considerably cheaper at the stated prices per pound.

TABLE V.

	Relative conductivity	Relative area for equal conductivity	Relative diameter for equal conductivity	Relative weight for equal conductivity	Relative tensile strength for equal conductivity	Weight of one mile of wire in pounds for equal conductivity	Present price per pound	Total price one mile of wire to give equal conductivity
Copper ...	100	100	100	100	100	1 in. dia. 163·2	$10\frac{1}{4}$d.	£6·93
Aluminium ...	61	164	128	48·5	75	0 in. ·128 in. dia. 79·5	15d.	£4·97 (28 % saving)

NOTE.—For aluminium wire in quantity, quotations of £140 per ton are given, which is equivalent to 15d. per pound, but for very large quantities still lower prices have been offered.

For small quantities the prices are higher, but even at $18\frac{1}{4}$d. a pound the price per mile is only £5·96.

*It is interesting to note that there is the same difficulty when making small high voltage motors, for in such cases it is not mechanically practicable to use wires as small as would be sufficient so far as conductivity is concerned. Some years ago the author suggested that they should be wound with iron wire.

TABLE VI.—*Some Users of Aluminium Wire for Electrical Power Transmission in America.*

Name of Transmission	Horse power transmitted	Length of line in miles	Voltage	Size of Wire (B. and S. Gauge)	Approximate weight of wire in tons
Snoqualine Falls to Seattle	12,000	32	30,000	·26-inches diameter	30
" " Tacoma		44	30,000	·23 " "	32
Mokelumine River to Stockton, California ...	1,300	43½	25,000	—	—
Tariffville to Hartford, Connecticut	2,000	33	10,000	¾-inch diameter	—
Kansas City and Leavenworth	—	76	—	—	—
Niagara Falls to Buffalo	15,000	22	22,000	3 cables each of 37 strands	—
Lewiston and Auburn Electric Co.	—	21	—	—	—
Boston and Maine Railroad	—	20	—	—	—
Boston Electric Lighting Co.	—	—	—	—	45
Shawinigan Falls to Montreal	10,000	85	50,000	3 cables each of 7 strands, No. 6	110
Massachussetts Electric Co.	—	—	—	—	220
Old Colony Street Railway Co.	—	10	—	—	—
Electra to San Francisco	13,000	154	60,000	3 cables each of 37 strands, No. 9	320
Colgate to Oakland	15,000	144	40,000	3 cables each of 7 strands	200
Sarnington River to Hartford	—	11	—	3 cables each of 37 strands, No. 3	—
Aurora Electric Railway	—	20	—	—	—
Chicago North-Western Elevated Railway Co. ...	—	20	—	up to 1½-inches dia. cables	70
Albion to Waterport, Orleans	400	6½	—	—	—
Telluride Power Co., Provo, Utah, to Mines at Mercur and Zintic	over 2,000	80	40,000	—	—
North Juba Power Co. to Sacramento	1,000	63	—	—	—
Ragged Rapids to Orilia, Ontario	2,000	18	—	—	—
Big Cotton Power Co. to Utah	500	—	—	—	—
Bay Counties Power Co., San Francisco, Cal. ...	—	90	—	equal to No. 6, copper	—
Standard Electric Co., San Francisco, Cal.... ...	—	200	—	—	—
City of Healdsburgh, Cal.	—	17½	—	½ No. 4 and ½ No. 10	—
Edison Electric Illuminating Co.	—	82	—	—	133
Shawinigan Falls to Sorel, Quebec	—	—	50,000	—	—
Siskiyore Electric Power Co., Fall Creek to Yreka, &c., Klaneath River, Cal.	1,000	63	22,500	3 strands, No. 4	—

Aluminium is said to fatigue sooner than copper, but nevertheless, as will be seen from Table VI, it is much used in the States.

One advantage of an aluminium line is that for equal conductivity it is only about half the weight of copper, and the span between the poles may, therefore, be much greater. On the Colgate and Oakland 142 miles transmission the spacing of the poles is 132 feet. On the original Niagara to Buffalo line with copper wires the spacing of the poles is 75 feet, whilst with the aluminium line which has been added later, the spacing is 112 feet. (See Table II.) In one transmission the span is 150 feet.

The heating effect for a given conductivity is smaller in aluminium wire, since copper, having a smaller surface, heats up more for the same C^2R effect.

JOINTS FOR ALUMINIUM CONDUCTORS.

As it is difficult to solder aluminium, a mechanical joint is generally employed, and when such a joint is made it is necessary that all the parts should be of aluminium, otherwise electrolytic action may take place.* The best known joint is the McIntyre, consisting of a double aluminium tube 9 inches long and $\frac{1}{16}$th of an inch thick, large enough to snugly enclose two wires. The whole is given several complete twists by clamping tools, and the joint is completed by turning back the projected ends of the wires as shown in Figs. 5. The Britannia joint is somewhat similar,

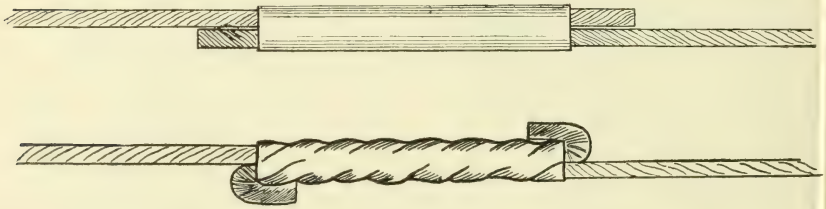


FIG. 5.
The Macintyre Joint as used for Aluminium and Copper Transmission Lines.

except that there is no tube, the two wires being independently twisted round each other and the ends turned back, to prevent them slipping through each other. It will be noted that a transmission line differs from a trolley wire in that increased size at the

* The tie wires for fastening aluminium lines to insulators should also be of aluminium, and in the case of copper they should be of tinned copper.

joints does not matter, and as there is no wear on the wire, a hardened outer skin is not so necessary.

Another joint consists of a double-coned aluminium tube, shown in Fig. 6. The wires are passed in through the ends and bent back

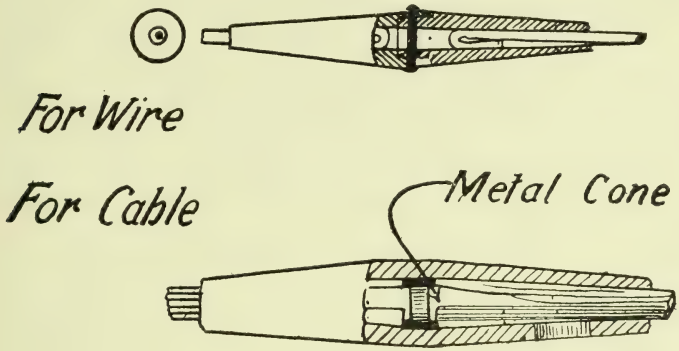


FIG. 6.
Double Conical Sleeves for Jointing Aluminium Transmission Lines.

on themselves, so as to wedge tightly into the space. The cones are then screwed together and made fast by a pin driven through the threaded portion.

Stranded cables may be connected by a double-coned tube and two round conical wedges, having axial holes through them, the middle wire of each cable end being thrust into these. Driving the wedges home, as shown in Fig. 6, expands the cables and prevents them pulling out.

HIGH PRESSURE INSULATED CABLES.

The record voltage for an insulated underground cable is employed on the Apple River to St. Paul transmission line, the pressure being 25,000 volts. At Reading, P.A., there is an underground cable a mile long, carrying three-phase current at 16,000 volts, for the Oley Railway. At Buffalo there are some 30 miles of rubber-insulated cables, which have carried 11,000 volts for the last seven years, and also 18 miles of paper insulated cable, which have worked at the same pressure since 1901. In this connection it may be of interest to mention that the first transmission from Niagara to Buffalo worked at 11,000 volts. When the load increased the pressure was raised to 22,000 volts, but rather than subject the insulation of the underground cables to this higher pressure a second

bank of transformers was installed, so that the energy from Niagara is first stepped up to 22,000 volts, and then reduced down at Buffalo in two steps, the first is 11,000 volts, and the second to pressure suitable for rotary converters and general supply.

The original paper insulated cables, from Deptford to Blackfriars, work at 11,000 volts, and the Metropolitan Electric Supply Company has about 40 miles of underground cable, at 10,000 volts. The Municipal systems at Glasgow and Manchester, the Midland Power Corporation, and the Northern Electric Supply Co. employ 11,000 volts, whilst the District Railway and the Metropolitan Railway have placed orders for 67 miles, and 45 miles of insulated cable respectively, at 11,000 volts.

Whatever we may do regarding the transmission of current by overhead wires in country districts there is no doubt that when such a line approaches a town it will have to be changed to undergound. If the transforming sub-station is some distance outside the town it may be that, in certain cases, two sub-stations will be necessary, as at Buffalo.

OVERHEAD HIGH TENSION WIRES IN THIS COUNTRY.

There is a growing feeling that if we are to do anything in long distance transmission of power in this country we shall have to employ overhead wires. As a matter of fact the Board of Trade is apparently very reasonable on this question, and several Power Bills have been passed, containing the following or a similar clause :—

"The consent of a rural district council as the local authority to "the placing of electric lines above ground. . . . . shall not *be* "*unreasonably withheld, and if any question arises whether that consent* "*is unreasonably withheld or not, that question shall be decided by the* "*Board of Trade.*"

As stated in Appendix B, overhead wires are proposed for the Snowdon transmission of power, and several other Power Companies are also about to employ them.

In this connection it may be interesting to quote a letter which the author has received from Mr. Charles H. Merz.

"I have to acknowledge your letter of February 2nd, in connection "with the above matter, and quite agree with you that, for extensive power "distribution schemes, overhead wires are essential.

"In the case of the Tyneside Power scheme, we have adopted three-"core paper insulated cables, laid on the solid system underground, for all "work in the neighbourhood of the towns. Now that the Company are extending into the outlying districts, however, it is proposed to ultilise overhead wires at 12,000 volts.

"I think the Board of Trade are now prepared to assist any carefully "considered proposal to use overhead wires in a suitable locality.

"On the Continent, overhead wires are in many cases put up under "statutory powers, which gets over the chief difficulty in this country, which "is that of getting wayleaves over private property. We may hope, perhaps, "that in the future, Parliament will be prepared to consider some such "proposal in sparsely populated areas."

The cable manufacturing companies naturally do not care for bare wires ; very few of them draw their own copper wire, and there is not much profit in merchanting bare copper. Their policy hitherto has been to become financially interested in the Power Companies, so as to sell their underground cables. This should be prevented in future, as the great expense of such cables is already a very heavy drag on more than one company.

To show the extent to which overhead lines are used abroad the United States Government Report for 1902, states that of the 125,000 miles of electric main and feeder cables in use only 8,124 miles or barely 6½ per cent. are underground. No less than 75 per cent. of the 3,700 towns with an electric supply have less than 5,000 population, and the bulk of these towns receive their supply through overhead wires.

LIGHTNING ARRESTERS.

Regarding lightning arresters, these have been developed to a really remarkable degree of perfection. The Siemens-Halske flare arrester is too well known to need description. There must be thousands in use all over the world ; it is at once one of the simplest as well as the most perfect pieces of electrical apparatus known.

The Wurtz non-arcing metal arrester is used for moderate voltages, and many engineers run galvanised iron barbed wires along the top of the poles, ground wires being carried down each pole to an earth plate.

There is also the ingenious water-jet arrester, which is used at the Vizzola Power Station in North Italy. In this apparatus the minute spaces between the globules of water in the jet effectively prevent the station voltage going to earth, but will readily pass a lightning discharge. The apparatus has the advantage that it is always ready, and there is nothing to burn up.

TELEPHONE CIRCUITS.

The telephone circuit comprises a *pair* of conductors usually carried on the same poles as the three-phase transmission line. The telephone wires are transposed relatively to each other at regular

intervals, so that the disturbing effect of the currents in the power-wires are neutralised and destroyed in the telephone circuit. In addition to transposition of the wires, there must also be symmetry between the two sides of the telephone circuit, for if one side is grounded, or has greater leakage than the other, or, if a telephone receiver is inserted in one side and not in the other, the dissymmetry produced may interfere with conversation. The potential in space in the neighbourhood of an extra high-tension transmission line is considerable, and may be such, that unless the telephone system is well insulated, the electrostatic stress will cause a breakdown. The telephone circuit must therefore be very carefully erected, and kept well away from the power wires.

On the Cauvery Falls line the telephone wires are carried by a separate small cross-arm placed six feet below the main wires. Transposition of the main line wires is made three times in the total length of 92 miles, and in the case of the telephone circuit at every fifth pole.

GROUNDED NEUTRAL OR PHASE WIRE.

There has been considerable discussion as to whether or not it is advisable to ground the neutral of a three-phase star connected system, and the balance of evidence is apparently in favour of it. Under normal conditions the potential between the conductor of a three-phase transmission circuit and the ground is $\frac{1}{\sqrt{3}} = 58$ per cent. of the line potential, but if the neutral is not grounded it may drift so as to increase the potential. For example, if one branch is partly or completely grounded, the potential between the other two branches and ground will be increased.

The advantage of grounding the neutral of a star connected system will be seen from the fact that a ground on any one of the three wires will be practically a short circuit to earth, and the transmission becomes inoperative. From the point of view of safety to life and prevention of fires this is desirable, especially if the low tension distribution is also grounded. Some engineers leave the fourth wire permanently grounded, and only employ switches on each of the three outside phase wires.

One way of reducing the amount of switching apparatus is to ground one of the three wires of the three-phase system as is done at St. Louis. On the switchboard there is a grounded bus-bar for one side of the system, so that single pole switches are possible, and the switching apparatus is thus greatly simplified. On the transmission

line the grounded wire is kept close to the pole and the two live wires occupy each end of the cross-arm.

It will be noted that in the case of a three-phase railway the grounded track rails form one of the phase wires.

STAR OR DELTA CONNECTED TRANSFORMERS.

The pros and cons as to whether the transformers on a transmission line should be connected up in Star or Delta have often been discussed, but no definite decision come to. Many transmission lines employ both methods, but the present tendency appears to be somewhat in favour of Star connection.

With Delta connection the greater number of turns in the winding, together with the necessary insulation between turns, necessitates a larger and more expensive coil, and this larger coil calls for a longer magnetic circuit and consequently a larger and heavier transformer.

In transformers of small capacity wound for high potential the cost and weight are therefore both considerably in favour of connecting the high-potential coils in Star.

On the other hand, Star connection requires the use of three transformers, and if anything goes wrong with one of them the whole bank is disabled. With Delta connection, one of the transformers can be cut out, and the other two will still be able to deliver three-phase power up to their full capacity ; that is, two-thirds of the entire bank.

Table VII gives a comparison of the line current, potential, number of turns, &c., of Star and Delta connected transformers.

TABLE VII.

Relation of Star and Delta connected Transformers.

	Line Current	Number of Turns	Insulation stress between Windings and Core
Star ...	100	58	58
Delta ...	58	100	100

TWO-PHASE AND THREE-PHASE TRANSFORMERS.

It may be of interest to mention that the (American) Niagara Falls Power Company and the Canadian Niagara Power Company (see Table VIII) are financially associated, and it is proposed to run the two power houses in parallel by means of triple conductor cables, carried over the Niagara River bridge.

TABLE VIII.

Particulars of the Six Power Stations now running or under construction at Niagara Falls.

	Name of Power Company	Eventual Total Capacity H.P.	Power of Turbine Plant	Effective Head Feet	Remarks
American Side	Niagara Falls Hydraulic Power and Manufacturing Co.— Power Station No. 1 ...	125,000	5 of 2,900 H.P. each 1 of 2,800 H.P. " 4 of 2,300 H.P. " 3 of 1,650 H.P. " 1 of 1,900 H.P. "	216	This Plant has been running several years
American Side	Niagara Falls Hydraulic Power and Manufacturing Co.— Power Station No. 2 ...	80,000	10 of 8,000 H.P. each	216	Now under construction
American Side	Niagara Falls Power Co.— Power Station No. 1 ...	105,000	10 of 5,000 H.P., 250 Revolutions	136	This Plant has been running several years
American Side	Niagara Falls Power Co.— Power Station No. 2 ...		11 of 5,000 H.P., 250 Revolutions	136	Now under construction
American Side	Lower Niagara River Power Co.	200,000	—	—	Franchise granted 1903
Canadian Side	Canadian Niagara Power Co. ...	110,000	5 of 10,000 H.P. 6 of 10,000 H.P. to be added later	158	Nearly ready
Canadian Side	Ontario Power Co.	400,000	50,000 H.P., now under construction	—	Now under construction
Canadian Side	Toronto Power Co.	—	—	—	Franchise granted 1903

NOTE.—It is estimated that half a million horse power will very shortly be transmitted from Niagara Falls. There is twenty million horse power available in the States, Switzerland and France have each ten million horse power, and Norway and Sweden about three million horse power.

The American Company has been working for some years, and it may be remembered that they started with *two-phase* 2,200 volts generators. They have been careful not to repeat this mistake in the new Canadian Company, the latter having three-phase generators giving 11,000 volts direct on the armature. In order to link the two stations together, electrically, so that if necessary one may help the other, C. F. Scott's system of two-phase, three-phase transformers is to be used. The author gave a diagram, explaining how this is done, in the "Electrical Review," June, 16th, 1889, and it is repeated in Fig. 7.

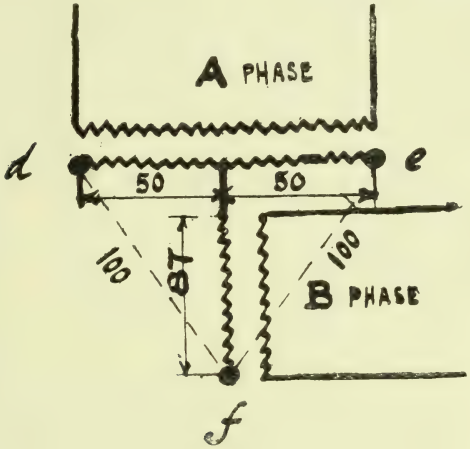


FIG. 7.

Diagram of C. F. Scott's Two-Phase, Three-Phase Step-down Transformers.

It will be seen that there are two single-phase transformers *A* and *B* and the ratios of the windings are so arranged that the voltages between the points *d e* and *f* of the three-phase connections are equal.

LAGGING AND LEADING CURRENTS.

On a long transmission line the question of lagging and leading currents is one of considerable moment, and some of the lines in America have become so extensive that the leading current caused by the condenser capacity of the line is not neutralised by the lagging current due to the inductive motor load.

The Telluride Power Transmission Company in Utah, for example, has no less than 300 miles of aluminium three-phase line working at 40,000 volts, from two stations 90 miles apart, the transformers being

Star connected and the neutral grounded. In one instance the leading current was so inconvenient, that it was necessary to operate one of the idle generators in the power house as a synchronous motor to give a lagging current to the line.

EFFICIENCIES.

The efficiencies of any given electric transmission from water power to the motor spindle, at the further end of a transmission line, may be roughly estimated as follows :—

	Full Load Efficiency.
Pipe Line	96 per cent.
Nozzle of Tangential Wheel	97 "
Tangential Wheel	82 "
Three-Phase Alternator Generating High-Tension Current	94 "
Transmission Line	90 "
Step-down Transformer	98 "
Three-phase Motor	92 "

Overall efficiency, 58 per cent.

That is to say, of the potential energy of the water, 58 per cent. is turned into useful work on the electric motor spindles. It would have to be a poor installation indeed to fall below 50 per cent.

Of the potential energy of coal only about 7 per cent. reaches the electric motor spindles, and whereas in the burning of coal future generations are deprived of its use, in the case of water the power is inexhaustible. The man who harnesses a water power does much more for humanity than one who exhausts a coal pit, and further, he does the work in a cleanly way, and not by befouling the atmosphere.

The only method of actually determining the efficiency of a pipe line is to measure, by means of the gauge, the pressure at the nozzle when closed and when wide open. The difference will represent the loss in the pipe line. If it differs much from calculation the extra loss may be due to eddies caused by the bends being too sharp or by rivets or joints or growths projecting into the pipe. These cause a contraction of the stream much greater than the apparent contraction in area of the pipe at the point of intrusion. Under the best conditions the efficiency may be 98 per cent, and under the worst 93 per cent.

The efficiency of the nozzle will depend largely on the care with which it is designed. Under very high heads (say) over 1,000 feet, the difficulty is to so design the nozzle that it shall discharge a solid stream without spray. Under the best conditions the efficiency may be 98 per cent., and under the worst conditions down towards 95 per cent.

The efficiency of a tangential wheel of large size and by a good maker, may be as high as 85 per cent., but 80 may at any rate be considered a good average. It is a peculiarity of the tangential wheel that the efficiency falls off very little with reduced loads.

Regarding the efficiency of the electrical portion of the transmission, most engineers who know anything at all about the matter will agree with the figures given above. Electrical plant is unique in that the efficiency can be predetermined and also found by actual test, with very great exactness.

APPENDIX A.

Two-Phase Transmission Plants for Mining Work.

Table IX gives particulars of some two-phase transmission of power plants which Messrs. Johnson & Phillips have supplied, in each case the transmission line being carried over extremely rough and mountainous country, on poles spaced 132 feet apart (or 40 to the mile). With the exception of the Rezende Gold Mines the poles are of wood obtained locally.

Those for the Rezende Mines are taper steel rivetted tubes in three sections, each 8 feet long, and they socket into each other. For convenience in shipment the sections are arranged to telescope.

When erecting the poles care is taken not to dig the holes of greater diameter than is absolutely necessary, and the bottom of the hole is

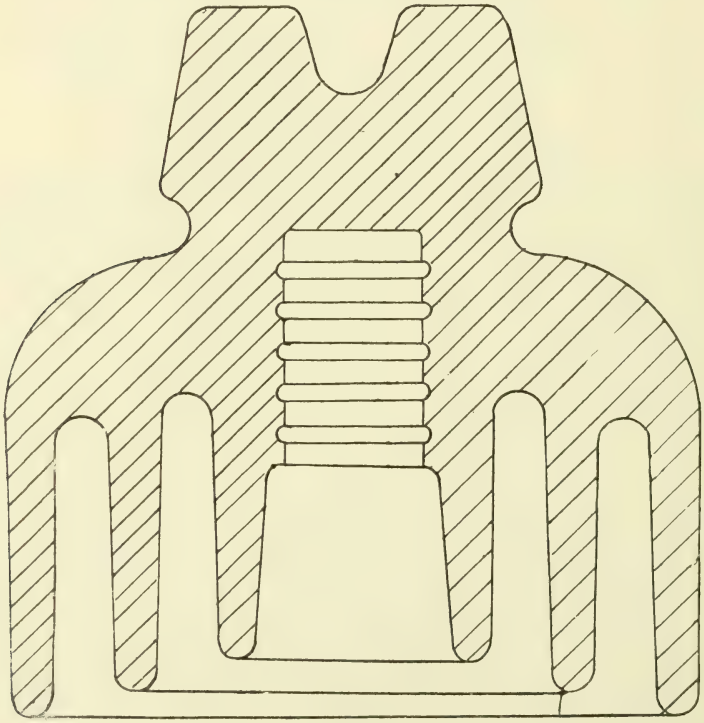


FIG. 8.

Insulator for 5,000 Volts. Raub Gold Mines.

TABLE IX.

Two-Phase Transmission Plants for Mining Work.

	Line Voltage.	Pelton Wheels.	Generators.	Exciters.	Transmission Line.	Transformers.	Motors.
Burma Ruby Mines	2,200	Pelton Wheel 180 H.P., 430 revolutions, 200 feet fall	Two-phase alternators, 140 K.W., 2,200 volts, 430 revols. Size of armature 54 ins. by 14 ins., 16 poles, 60 periods	Direct driven shunt wound 50 volts, 60 amps.	14,000 yards No. 2 S.W.G. on 60 wooden poles	2—50 K.W. transforming from 2,000—100 volts	2—50 H.P. at 773 revols. 100 volts, coupled to 12-in. centrifugal pump. 2,000 galls., 40 feet head
Raub Gold Mines, Pahang	5,000	3 Pelton Wheels 290 feet head on girder frame, direct driving alternators.	3—150 K.W., 380 revols. Size of armature 66 ins. by 13 ins., 32 poles, 5,500 volts, 50 periods	Exciters 5 K.W., 50 volts	Total 30 miles, ·252-inch diameter copper wire, 40 poles per mile, 300 oak cross-arms, 5 sets of lightning arresters, also barbed wire	6—50 K.W. and 1—50 K.W. as spare, 5,000—220 volts	2—100 H.P. at 580 revols. 2— 25 H.P. at 845 revols. 2— 15 H.P. at 1120 revols. 2— 10 H.P. at 1120 revols. all 220 volts
Burma Ruby Mines 2nd Extension *	2,200	1 Pelton Wheel 180 H.P., 430 revolutions, 200 feet head	1—140 K.W., 2,200 volts, 450 revols. Size of armature 54 ins. by 14 ins., 16 poles, 60 periods	Exciters 60 volts, 780 revols.	22,000 yards No. 2 S.WG. 150 oak cross-arms, 500 insulators, 4 sets lightning arresters	4—40 K.W. without cases, 2,000—200 volts	2—50 B.H.P. 900 revols. 1—10 B.H.P. 900 revols. 200 volts
Rezende Gold Mines, Rhodesia	2,200	Pelton Wheels 225 H.P., 400 revolutions, 312 feet head	1—Two-phase 170 K.W., 400 revols. 50 periods, 2,200 volts	Rope driven exciter 1,400 revols.	Stranded copper cable, barbed wire on on poles for lightning arrester.	2—15 K.W. 2,000—220	1—50 H.P. 750 revols. 2,000 volts. 2— 5 H.P. 3—10 H.P. 1—15 H.P. for 220 volts

* Note.—A third similar extension plant has recently been sent out.

laid over with concrete. When the pole is in position the earth is well rammed into the hole, or, if the ground is poor, the hole is filled up with stones, and cement poured in to make everything solid.

The cross-arms are of oak, and each is provided with four holes to receive the insulators, which are complete with bolts, nuts and washers. Fig. 8 shows the insulator used for the Raub Gold Mines. The two conductors belonging to one phase are on one side of the pole, and the two conductors belonging to the other phase on the other. The line wire lies in the top groove of the insulator when running on the straight, but when the wires approach the insulator at an angle when going round curves the wires are attached to the circular groove. After binding with copper wire the whole is sweated up solid with solder, resin only being used as a flux.

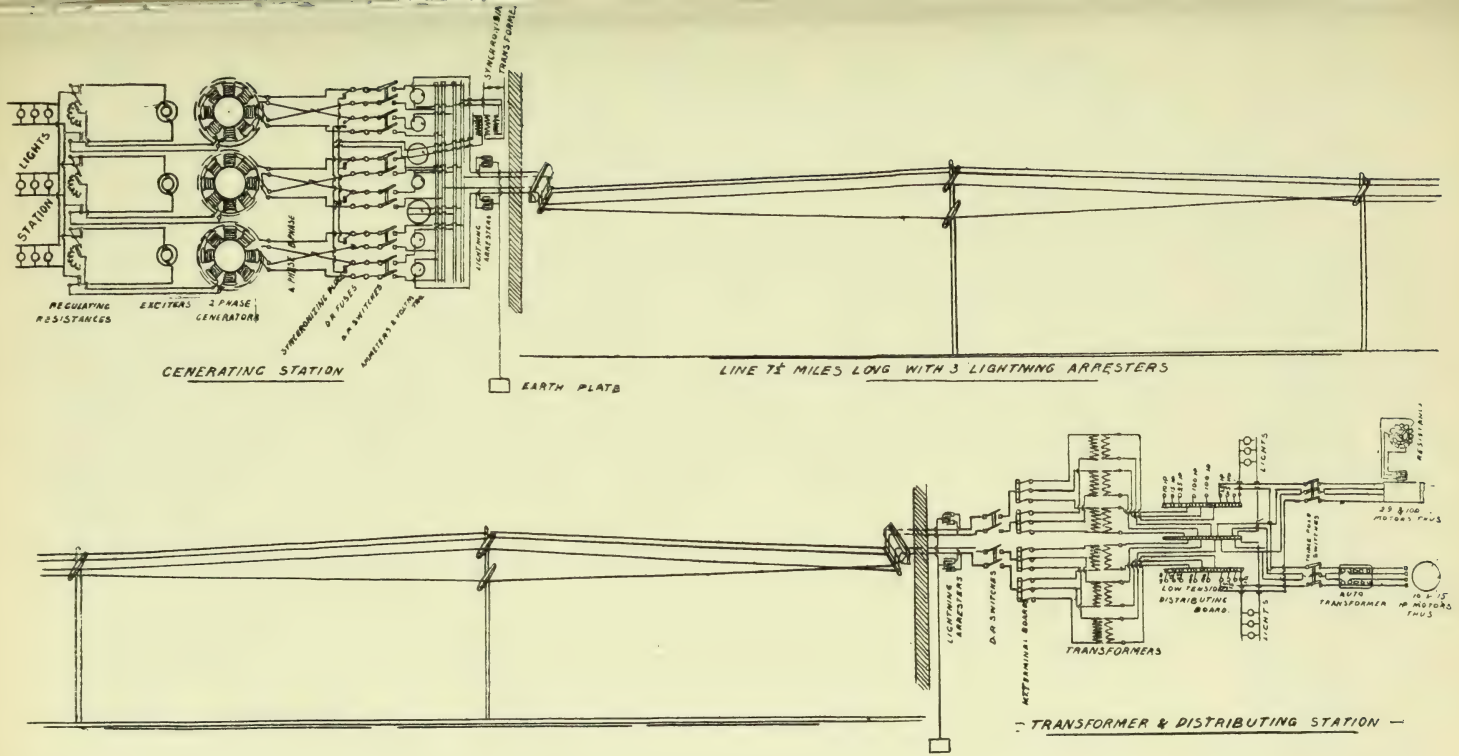
Before finally fixing the cable to the insulator the strain is adjusted to allow for the atmospheric temperature at the time, the dip of the wire at the centre of span being as follows, this also applying to the telephone wires :—

Temperature Fah.		Dip in centre of span.
60 degrees	...	16 inches
70 "	...	18 "
80 "	...	21 "
90 "	...	23 "
100 "	...	25 "

Two of the transmission wires run parallel from end to end of the line, that is to say, the one nearest to the pole at the power house remains nearest right through. The two transmission wires on the other side of the pole, however, are crossed about once every few miles as shown in Fig. 9, so that the wire which starts at the power house nearest to the pole will at that particular point be crossed over until it is the wire furthest from the pole. Two cross-arms are required at this crossing over point, and as the side stress on the insulators is considerable, extra care has to be taken in fixing them.

The joints in the transmission wires are made by inserting the wires through a thin copper tube and then twisting the whole together, as shown in Fig. 5. The interior of the tube is tinned and the ends of the cables well cleaned and dipped in powdered resin before inserting into the tubes, then *after* the joint is twisted up the whole is sweated together with solder.

The telephone wires are No. 14 S.W.G. copper, carried on insulators about two feet below the cross-arm, except for Raub, where they are on separate poles. They are rotated round each other at every fourth pole, to neutralise induction effects.



RAUB MINING PLANT

FIG. 9.

DIAGRAM OF MAIN SWITCHBOARD LINE & DISTRIBUTION BOARD.

As a protection against lightning, the Rezende and Raub installations have barbed wires run along the top of the poles. They are strained in accordance with the following table :—

Temperature Fah.		Dip at centre of span.
60 degrees	...	17·5 inches
70 "	...	20·0 "
80 "	...	21·0 "
90 "	...	23·0 "
100 "	...	25·0 "

All metal poles fixed in moist ground make sufficiently good contact with earth, but when in dry or rocky ground, or if cement is put round them, contact is provided by sinking a galvanized iron plate two feet square in the ground in a damp place in the vicinity, and connecting up by a piece of barbed wire. It is most important that good metallic contact is made at all points, and where a good ground connection is quite impossible, the barbed wire is not attached metallically but rests on an insulator raised above the pole. In the case of wooden poles a length of wire is run down each pole and connected to the earthplate.

At the terminals of the transmission line each wire is carried inside the buildings, and secured to a shackle insulator attached to a wooden beam well inside the buildings, a weather board being fixed outside to prevent rain from blowing in. Insulated conductors are jointed to the lines and carried down to the switchboard, the top of the wire being bare and the bottom part insulated, the two being separated by an oil cup insulator. Lightning arresters are fitted inside the wall and bare wires from the line carried down to these, a copper earthplate being sunk in a convenient position in the ground in moist earth.

In giving detailed particulars of the Burma and Raub plants the author has thought it would be of interest to state the approximate prices, and also to give an idea as to the tools, spare plant, and other extras which must be shipped with such an installation as that for the Raub Mines.

Detailed Statement of Plant for Burma Ruby Mines, Ltd.

Two-Phase, Two Miles Transmission, 170 *Horse Power,* 2,000 *Volts,* 60 *Periods.*

Generating Plant.—

One Pelton wheel, with double nozzle to give 180 horse power on a 200 feet fall, with steel junction box and governing gear.

Two-phase alternator to give 140 K.W. at 2,200 volts, when running at 450 revolutions. Size of armature 54 inches by 14 inches, 16 poles.

One exciter, 6 K.W., 50 volts, with spare armature.

Ropes and belt—10 ropes, 1¼-inch diameter, and 100 feet of 5-inch belting.

Main switchboard with 2 switches, 2 ammeters, 1 electro static voltmeter and a resistance £1,200

TRANSMISSION LINE.—

Four sets double-pole lightning arresters.

Copper line wire—14,000 yards of No. 2 S.W.G.

Cross arms—84 of oak.

Telephone—2 sets brass bound instruments, and 3½ cwts. No. 14 wire.

Switchboard for mine, with high tension fuses.

Four transformers of 30 K.W. each, with spare coils £650

MOTORS AND LIGHTING.—

Connection from transformers to 3 motors, 1,900 yards of 19/14 cable.

Two pumps, 12-inch Gwynne, each with a 50 horse power motor, also sliding suction and foot valve.

Washer motor—40 Brake Horse Power, 200 volts, 800 revolutions, with friction gear arrangement.

Arc lighting plant—Two 7½ K.W. transformers, 10 arcs, 1 switchboard, 10 winches, 500 feet steel wire, 500 yards 7/16 cable ... £1000

For the above plant the approximate price per horse power delivered is £17.

The above is only one of the plants—three similar to it are now running.

One of the plants for the Burma Ruby Mines arrived during the wet season, when the roads were impassable; the native workmen, therefore, took to pieces the Pelton wheel and governor, also the alternator, including even the armature core plates, and all the other machines, motors, pumps, &c. The whole was carried up country on mule back and was entirely erected by native labour. It has worked without a hitch from the commencement, and the installation furnishes a striking example of how, by the adoption of electricity, an undertaking which could not previously pay dividends was made a great success. Before installing the electric transmission plant it cost £6,000 per annum at the mines for fuel and lighting, and the Chairman of the Company went so far as to say in public that if worked in the old-fashioned way the concern would never have been placed on a paying footing. After the power plant was installed, the Directors reported in September, 1899:—

"The machinery for working the mines by electricity, which started "on the 5th September, 1898, and was in full operation at the commencement "of the present year, has proved an unqualified success, and has reduced the "expenses by £500 a month. So successful, indeed, has the installation "proved, that the Board has determined to double it."

Ten months later the Directors reported :—

"The second electrical power plant, which commenced running on "April 7th last, has proved as great a success as the first, which has now "been working for eighteen months."

Detailed Statement of Plant for the Raub Gold Mines.

400 *Horse Power*, *Two-Phase Transmission*, 7½ *Miles*, *at* 5,000 *Volts*, 50 *Cycles per Second.*

Generating Plant.—

Three Pelton wheels, one being spare, to work on a 290 feet head, and run at 386 revolutions.

One receiver of mild steel, with taper branches for the wheels, flanged one end for pipe, with manhole and relief valves.

Three alternators, 150 K.W. two-phase 5,000 volts, 51 cycles, coupled direct to the Pelton wheels.

Three exciters for above, 50 volts.

Three tachometers.

Main switchboard and connections also.

One ohmmeter, 200 volts (Evershed).

One meter bridge.

One sensitive portable galvanometer.

Twelve Leclanche cells.

Six electric hand lamps £3,200

Transmission Line.—

Transmission line, consisting of 30 miles of No. 3 S.W.G. hard drawn bare copper wire.

300 galvanised pole caps and iron clout nails.

300 bolts for fixing cross-arms to poles.

1,200 insulators with arm studs (20 for spares).

1½ cwt. tinned copper binding wire.

200 yards 19/16 wire, leading in cable.

Lightning arrester, 3 sets along route, of Siemens & Halske pattern. One set at generating station, and one set at mines, of Wurtz type.

Barbed wire, 15 miles galvanized, also 2,000 feet No. 10 S.W.G. iron wire and 750 wire staples.

High tension line terminal board.

Transformers, seven of 50 K.W. each (one spare) to reduce from 5,000 to 220 volts.

Distributing board for motor circuits.

Telephone service complete, 15 miles 14 S.W.G. hard drawn copper wire.

600 insulators, mounted on brackets to screw into wooden poles.

2 telephones complete, with transmitters, receivers, call bells and batteries.

100 yards No. 18 leading in wire.

4 Cardew earthing devices, for telephone circuit.

3 6-inch bells to ring in different parts of mill.
3 relays and spare wire.
12 Leclanche cells.
220 yards, No. 16. bell wire
6 telephone plug fuses.
2 strong watertight bell pushes £1,900

MOTORS AND LIGHTING.—
Two 100 H.P. motors, 220 volts, 580 revolutions, with wound rotors.
Two 25 H.P. motors, 220 volts, 845 revolutions, with wound rotors.
Two 15 H.P. motors, 220 volts, 1,120 revolutions, short circuited rotors, and auto-transformers.
Two 10 H.P. two-phase motors, 220 volts, 1,120 revolutions, short circuited rotors, and with transformers.
Ten cotton ropes, 1¼-inch diameter.
One centrifugal pump, with motor to raise 12,000 gallons per hour to a height of 45 feet.

ELECTRIC LIGHTING.—
100 16-C.P. lamps.
100 pendant fittings, each comprising—10-inch enamelled steel shades, bayonet lamp-holders with shade carriers, porcelain ceiling roses with fuses, and 6 feet flexible twin wire.
50 5 amp. tumbler switches.
50 5 " fuses.
5 25 " D.P. switches.
5 25 " D.P. switches.
110 yards 7/16 cable.
55 " 7/20 "
275 " 3/22 "
Also sufficient quantity of insulating material, wood cleats, screws, wood blocks, &c. £1,600

TOOLS.—
For Fitters.
Lifting tackle—one 7½ tons brake block.
" " one 5 " "
1 6-inch gap lathe and tools.
2 bench vices.
6 fitter's hammers.
1 14 lb. sledge hammer.
12 assorted files.
12 " chisels.
1 tape measure, 100 feet.
1 " " 50 "
2 light blocks and falls, with rope.

For Splicers.
2 marlin spikes.
6 needles.
2 palms.
2 knives.

For Electricians.

20 lbs. No. 18 tinned copper wire.
4 lbs. black prepared tape, 1-inch wide.
4 lbs. " " ½-inch "
2 lbs. Chatterton's compound.
56 lbs. resin.
56 lbs. special solder.
4 pairs pliers, 10-inch, 8-inch, 6-inch and 8-inch gas.
2 soldering bits.
2 linemen's stoves.
4 pairs draw tongs.
2 6-inch metal pots and 2 ladles.
1 speed counter £70

SPARE GEAR.—

For Station.

1 cwt. armature wire.
½ cwt. magnet wire.
12 armature coils.
3 magnet spools.
All necessary insulating material for above.
6 pairs indiarubber gloves.

For Pelton Wheels.

12 wheel buckets.
1 coppered spear, with short and long screwed rods, gun metal stuffing glands, worm, worm wheel and bracket.
1 pair sprocket wheels and 2 chains.
4 nozzles.
1 pair bearing brasses.

For Line.

4 dozen triple petticoat insulators, with bolts complete.

For 10 *H.P. Motor.*

2 pairs brasses for bearings.
2 terminal blocks.
44 lbs. insulated copper wire.

For 15 *H.P. Motor.*

2 pairs brasses for bearings.
10 terminal blocks.
55 lbs. insulated copper wire.

For 25 *H.P. Motor.*

2 pairs brasses for bearings.
10 terminal blocks.
88 lbs. insulated copper wire.
6 copper gauze brushes.

For 100 *H.P. Motor.*

2 pairs brasses for bearings.
3 Stabilit brushes for terminals.
150 lbs. insulated copper wire.
6 copper gauze brushes £150

For the above amount of plant the approximate price per horse power delivered is £17, this including one spare generating unit.

Being in the Straits Settlements the Raub installation was mainly erected by Chinese, under the direction of the two Engineers, Messrs. J. & B. Rance. The whole installation went from start to finish without a hitch, and the author doubts whether if the generating plant had been steam and the electrical machinery of the continuous current type the same results could have been obtained. Multiphase electric generators and motors, &c., are about as reliable as machinery can well be, and if it is possible to use Pelton wheels for generating the power, then the whole plant attains a simplicity which is quite unique.

One remarkable thing about these multiphase plants for mining work is the complete changes which such an installation makes in the ideas of the mine officials. From being in awe of it, they soon get on familiar terms, and the smooth working and steading running of the motors appeal to them, and new possibilities of development open up which they are not slow to seize.

For example, the Manager of the Raub Gold Mines, Pahang, wrote :—

> "Electrical power was new to me, and I dare say I was a little prejudiced, and until I saw the plant started I was doubtful of its working well and giving satisfaction. In the face of such constant and excellent work during the past two months, I am getting confidence in it, and as the present spare power costs us nothing we ought to use it for every possible purpose."

At a later date the Manager reported to his Board as follows :—

> "There have been very heavy rains and thunderstorms during the month which severely tested the installation, but did not damage nor in any way interrupt the work."

The mill works night and day, and when thunderstorms do occur they are of the tropical variety, very severe and frequent.

APPENDIX B.

The North Wales Power Transmission.

The Transmission of Power Scheme for North Wales is essentially on the lines sketched out in this paper, namely:—The utilisation of *high falls*, and the transmission of three-phase current over *bare wires at high* pressure. As the proposal is somewhat unique for this country, a brief description may be of interest. The principal object is to establish central Power Stations to supply energy in bulk to the various Railways, Quarrys, Towns, &c. The power of certain lakes situated at a high altitude is to be utilised, the falls being exceptionally high for this country; in the case of Lake Llydaw on Snowdon 1,150 feet, and in the case of Lake Eigau in the Conway Valley 800 feet.

The Snowdon Power Station is being carried out first, and the contract for the work is in the hands of Messrs. Bruce, Peebles & Co., of Edinburgh. The Consulting Engineers are Messrs. Sir Douglas Fox and Harper Bros. & Co.; the author advising on hydraulic and electrical details.

RAINFALL.

Dealing first with the question of water supply and rainfall area, when the author first investigated the matter he was surprised to find how very high and well sustained the average rainfall was. Indeed it would appear that Snowdon can claim to be the wettest point in Europe, its estimated average for the last ten years being over 190 inches, as against 170 inches for the Sty in Cumberland. The figures given in "British Rainfall" are as follows:—

		1900.	1901.
Snowdon (Llydaw)	1,450 feet ...	193·50 inches ...	169·50 inches.
" (Glaslyn)	2,500 " ...	173·60 " ...	186·70 "

The reason for this high rainfall on Snowdon appears to be due to the fact that it is in the track of the Atlantic depressions, and is surrounded from the South and North-West by low-level valleys radiating down to the sea, and along which atmospheric moisture is carried. When the wind blows from any wet point the moisture is driven up towards the high regions, and being condensed at a high elevation is discharged in the form of rain or snow on the sheltered or Eastern side on which are the Lakes Glaslyn, Llydaw, and Teyrn. (See Fig. 10.)

FIG. 10.

Plan showing the Llyn Llydaw Watershed on Snowdon.

To show what a phenominal rainfall there is at Snowdon it may be mentioned that the total for 1903 was over 250 inches, over 100 inches having fallen before May 21st. Some of the records taken by Mr. Gethin Jones, are as follows :—

May 21st to September 8th	... ...	60·10 inches.
September 8th to September 9th	...	5·30 "
September 9th to September 11th	...	4·12 "
September 11th to October 23rd...	...	30·20 "

At the Pen-y-Pass Hotel on the top of Llanberis Pass, nearly seven inches of rain fell in the 22 hours, from 11 p.m. to 9 p.m. on the 15th. At Glaslyn there would probably be a couple of inches more.

The dimensions of the three lakes mentioned above are :—

Name of Lake.	Height above sea level feet.	Extreme length in feet.	Mean width in feet.	Maximum depth in feet.	Approximate area in square feet.
Llydaw ...	1,416	5,808	930	150	5,400,000
Glaslyn ...	1,970	1,600	582	125	930,000
Teyrn... ...	1,238	725	305	—	220,000

The water from Glaslyn runs into Llydaw and the watershed area is well defined, because for a considerable distance it runs along the summit ridge of Snowdon. The watershed area feeding Lake Llydaw may be taken to be about $1\frac{3}{4}$ square miles, or (say) 47 million square feet. As a matter of fact the actual area of the land surrounding the lakes is, of course, very much more than the plan area, for the mountain rises steeply from the lakes.

PIPE LINE.

The overflow from Lake Llydaw runs down what are known as the Cwm Dyli Falls to Lake Gwynant; the total head from Lake to Power Station being 1,150 feet in a total pipe line length of 6,500 feet. The pipes are in duplicate, 30 inches and 27 inches diameter, and $\frac{5}{16}$ to $\frac{5}{8}$-inch thick; they are by Messrs. Mechan & Sons, and Messrs. Stewart & Lloyd. It is proposed to utilise the full 1,150 feet fall, but it may be mentioned that the main Fall of 750 feet is immediately above the Power Station, and as it taps another watershed lower down the mountain, an additional storage reservoir can be made at this point. The lake can be raised 20 feet by a dam only 100 feet long.

EVAPORATION, &c.

An important point when considering the question of water power and rainfall area, is how much is likely to be lost by evaporation, absorption and percolation. It happens that Llydaw watershed is extremely well situated from this point of view, for owing to the general prevalence of rain and mist on the mountain, the humidity of the air for a considerable portion of the year is above the saturation point, when no evaporation can take place. Again, much of the surface of the Llydaw watershed is made up of bare rock and stones, from which the water quickly runs off, and when once the surface gets dry there is, of course, no moisture to be evaporated.

As regards percolation, the ground underlying the watershed is made up of hard and impervious rocks of the primary formation, and it has been noticed that the rivers running along the low level valleys around Snowdon run low in a short time during dry weather, proving that percolation is very small.

Taking everything into account it is probable that the total loss will be less than at Thirlmere in Cumberland, where careful records over a number of years have established an average of 8 inches per annum. The greatest loss takes place from the surface of the

Lakes, and is probably about 12 inches a year, but as the area of these is only about $\frac{1}{6}$th of the watershed the total loss is not likely to exceed 8 inches, or say 5 per cent. of the annual rainfall.

SYNCRONISM OF POWER WITH LOAD.

When investigating water systems for electric power purposes it is necessary to consider how the load is likely to vary in relation to the water supply. In North Wales, for example, slate quarrying is only carried on during *daylight hours*, and consequently during the midwinter months, when Snowdon summit is receiving more snow than rain, the demand for electric power at the quarries will be lowest. Again, it happens that the period of minimum rainfall on Snowdon is at the beginning of summer, whilst the heaviest rainfall of the year is usually in August. As a consequence the melting of the snow at the approach of summer helps to average up the supply.

In Switzerland many of the mountain railways are worked from mountain torrents, the small feeding streams of which freeze up in mid-winter. These railways, however, mainly exist for the convenience of tourists, so it happens that there is the greatest water supply at the time when most required. Again, at Tacoma, U.S.A., a glacier having an ice cap 250 feet thick feeds a stream which is carried through 1,700 feet of piping at an angle of 45 degress down to the wheels, the pressure being 400 pounds per square inch; about 40,000 horse power can be developed, and in this case the glacial flow is greatest in the dry season, because the ice cap is then melting rapidly. It has also been found that there is a daily glacial tide, caused by daily fluctuations in temperature, and this results in the delivery of the maximum amount of water between 5 p.m. and 11 p.m., which are the hours when for the lighting and tramway services the demand on the Electric Supply Station is heaviest.

POWER HOUSE.

The Snowdon Power House is a substantial stone building, 135 feet long by 40 feet wide, and the first instalment of the equipment is four 1,000 kilowatt sets, each consisting of a double tangential water wheel coupled to a three-phase alternator, giving 11,000 volts and 40 periods per second. The exciters are driven direct, and the governors are of the Ganz type, similar to those in use in the Valtellina Power House.

TRANSMISSION LINE.

The transmission lines will be of bare copper wires, ·324-inch diameter, arranged triangularly on telegraph pattern wooden poles, the insulators being as shown in Fig. 11. Quite a large proportion

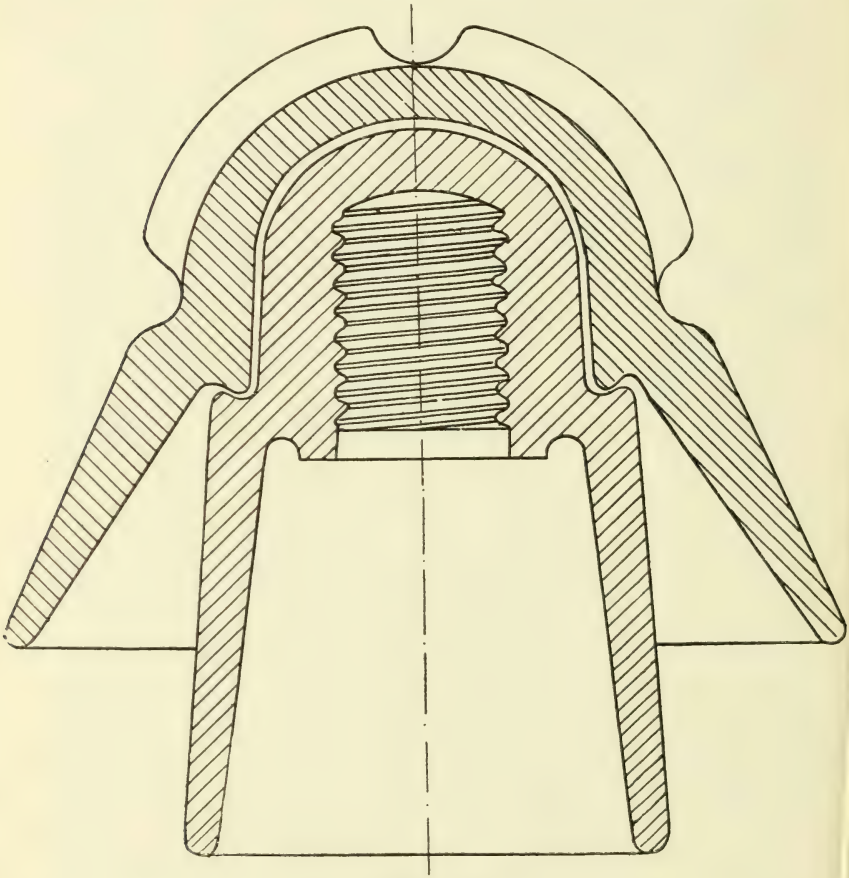


Fig. 11.
Insulator for Snowdon Transmission.

of the transmission line will be carried alongside the track of the railways which the Company are building or taking over. Thus from Snowdon to Portmadoc the line follows the railway all the way, and at Beddgelert the line to the Nantle Quarry district and to Carnarvon branches off along the North Wales Narrow Gauge Railway, which the Company has taken over, and is extending to Beddgelert at the one

end, and from Dinas to Carnarvon at the other. Eastwards, from the Power Station, the transmission line will follow the proposed Light Railway to Capel Curig and Bettws-y-Coed, and afterwards be continued Northwards to the other Power Station near Trefriw, in the Conway Valley, and so on to the towns along the Coast. In a Westward direction it passes over the Llanberis Pass to Llanberis, where a branch will be taken over the mountains to the Penrhyn district and to Bethesda, &c. In case it is necessary to connect with Blaenau Festiniog it is an easy matter to carry a line in that direction. Of course, where necessary, to meet B.O.T. wishes, and in the towns, the cables will be underground. The approximate distances from the Snowdon Power Station are :—

To Beddgelert	6	miles.
" Llanberis	7	"
" Portmadoc	12	"
" Criccieth	16	"
" Carnarvon	16	"
" Capel Curig	7	"
" Bettws-y-Coed	11	"
" Llanberis Quarries	8	"
" Nantle Quarries	11	"
" Penrhyn Quarries	12	"
" Blaenau Festiniog Quarries... ...	7	"

The loss in the transmission line to any of these points will not exceed 10 per cent., and in the majority will be much less.

As a matter of fact, 5,000 horse power is being transmitted to the Kolar Goldfields, Mysore, a distance of 92 miles, with a loss of only 13 per cent. The voltage is 30,000, and current is carried by a duplicate line, each consisting of three wires ·324-inch diameter.

DISCUSSION.

Mr. Haarer

Mr. Ernest C. Haarer said—The author states that the safe limit of a lead socket joint is probably about 500 pounds per square inch, and I would like to ask whether the Pikes Peak pipe line is jointed in this manner, and, if so, may it be taken as an ordinary lead caulked joint, or one in any way specially constructed to avoid the forcing out of lead? I have always been under the impression that a head of 700 feet was the maximum with an ordinary lead joint.

Referring to the author's remarks on the furring up of pipe lines, it would be interesting to hear whether he knows of a case where any special type of scraper has been used for cleaning the bore of any of the large diameter pipe lines mentioned in his paper. I believe the 10-inch water mains at Torquay, and which are some 14 miles in length, are annually cleaned out by a specially constructed scraper at a cost of about one-tenth of a penny per yard.*

It would appear that any method of governing by deflection of nozzle jet, or by the splitting and opening of the two halves of wheel, would destroy the efficiency of motor, and perhaps the author will be good enough, if he has the information, to state the approximate efficiency of the Cassel wheel under sudden and varying loads. And I would here suggest that there is another method beyond those mentioned by the author on page 213, of sensitive governing under high heads, the other being the automatic adjustment of nozzle area to suit the varying power required, and a number of motors are so, and successfully, governed in this country.

After some few years' experience with a number of Pelton wheels of small size, viz. :—from 12 inches up to 36 inches diameter, and most of them working from a pressure of 750 and 1,050 pounds per square inch, I would like to instance, as confirming the author's remarks *re* the small wear, &c., with these motors, a case in this City where a 12-inch motor running for several hours daily at full load showed after $4\frac{1}{2}$ years running, during which it had made over 1,100 million revolutions, no appreciable wear either in the bearings or in the buckets, and at the end of this period ran as well as when first put up.

* See paper read by W. Ingham before Inst. Mech. Eng. in 1899, entitled—"Incrustation of Iron Pipes."

Further, not a penny piece had during this time been spent on the machine either in repairs or renewals, nor had the least trouble ever been experienced with it in its workings. Mr. Haarer

Mr. Alex. H. Robinson said—Probably the comparatively low efficiency of the Pelton wheel (80 per cent.) is due to the second principle enunciated by Borda, *i.e.*, "and quit the wheel without velocity" not yet having been attained. It may be of interest to the members to hear of some troubles experienced by the San Joaquin Electric Co. (referred to by the author), owing to the antics of the high pressure water *after* leaving the wheel. Mr. Robinson

Mr. George P. Low, the Editor of the *Journal of Electricity*, of San Francisco, thus recounts the phenomena:—"The wheel pit, "which is of solid masonry contruction, was carefully closed over by "heavy planking. Upon turning on the water, it refused to go through "the tail race and along the bottom of the ditch, but, instead, rolled "up the sides of the pit, or followed up the water wheels to the plank "covering and along the under side of the planks it rushed madly out, "almost horizontally for a distance of 60 feet, where it struck a great "granite boulder and was lost in spray. The jets strike the wheels at "an angle of 45 degrees from the horizontal, and the nozzles being "deflecting, the impact water strikes the bottom of the wheel pit with "terrific fury. After two days operation, the water had cut under "the concrete and into the seams of the bedrock, coming out in the "power house and outside of it."

The report then proceeds to give several experimental remedies, including a $\frac{3}{8}$-inch steel plate, which was worn through in two days, and concludes with—

"The heroic method of feeding a fresh cast-iron plate, $1\frac{1}{2}$ inches in "thickness (under the wheel) to it as often as necessary has now "been resorted to as the best solution of the problem.

I should much like some information as to the effects of intense frost on the pipe line. I do not know whether it is the usual practice when the wheels are not working to turn off the water through a bye-pass valve, but if not, is any trouble experienced through frost?

I noticed (during the Swiss visit of the Institution of Electrical Engineers) that the pipe lines for the most part were not covered in any way, but I was unable to get any information on this point.

Regarding "lightning arresters," I do not anticipate that there will be any trouble from lightning in this country. In Switzerland, where there are hundreds of high tension lines all over the country, including the mountainous district, and where the thunderstorms are

Mr. Robinson exceptionally severe, they did not seem to be troubled in the least from this.

It seemed to be the usual practice in Switzerland to completely surround the high tension wires (where they crossed public roads) by a galvanized iron net-work. This makes a very safe arrangement, and is not at all obtrusive.

Mr. Molesworth Mr. W. H. MOLESWORTH said—The subject which the author has chosen for his paper is so large and of such a general character, that it is impossible to discuss more than a portion without occupying too much space. I propose confining my remarks to the electrical transmission line, which is the most important feature in such a plant, and which, by the way, cannot be claimed as a special monopoly of water power schemes.

The limitation of voltage on overhead transmission lines has not yet been fixed, but energy losses, capital expenditure, &c., have hitherto determined the pressure. The loss of energy permissible in a transmission system depends on commercial conditions, or in other words, the economical limit of efficiency is fixed by the cost per unit of energy, and this must depend not only on the energy losses, but also on working expenses and capital outlay.

The last paragraph under this heading is: "In this country, with its "fog and smoke, probably 20,000 volts would be about the limit. "Comparatively short distances do not call for more." As regards high head water powers, this statement is justifiable, only on the grounds that, generally speaking, where high waterfalls are found in Great Britain their volume is so small, that the transmission over long distances is out of the question.

Fog, smoke and dirt, as generally found near our large towns, certainly form a difficulty in maintaining a very high insulation, and if, for instance, 40,000 volts were necessary, special precautions might be required. It is, however, possible that in the next ten years we shall have a 60-mile transmission line even in this country, and in that case, we should probably also have a much higher voltage than 20,000, although the original power will be coal and not water.

There is a feeling of distrust among public authorities in this country towards high voltage transmission lines, which is due to ignorance. Having lived for several years on the Continent, surrounded by such transmission lines, I can say that there is no safer method of transmitting power in existence.

The ordinary 500-volt tram line system comprises not only an uninsulated return with a bare overhead lead but also the continual

pressure of a moving contact maker, and yet such trolley wires are to be found over the most crowded thoroughfares in many towns of Great Britain. On the other hand, overhead transmission lines run for the most part over agricultural country, and it is safe to say, that the chances of injury to the public and their property is not such an anxiety to the Engineer as is the stealing of his copper conductors. Mr. Molesworth

Experience of long distance transmission lines with water power in this country may be said to be nil, and as we do not equip such lines on the Continent or in America, our attention is necessarily directed to the Colonies, where the following conditions require special attention :—

(1) *Temperature.*—The thermometer may register 120 in the shade, but no shade is possible for transmission lines.

(2) *Rainfall.*—The line may pass through country, such as that of the Northern Punjab, where in parts the rainfall is 3 inches in the year, and this 3 inches falls during twenty minutes; or, again, in places like Cherrapunji, where the rainfall often exceeds 800 inches per annum.

(3) *Lightning.*—In tropical countries lightning is very severe, but it is not a serious obstacle with modern arresters.

(4) *Dust-storms.*—In Australia and India dust-storms are perhaps the greatest difficulty, both as regards short circuiting of conductors and the maintenance of insulation between wires and earth.

(5) *Cyclones.*—In severe cyclones the pressure against poles and line may reach 50 to 100 pounds per square foot.

(6) *Zoology.*—Steel poles, or at least metallic bases, are absolutely necessary to guard against white ants, as in the case of a wooden pole, their presence will only be discovered when the pole has collapsed. These little animals will bore up through the hardest woods, through leather, or the bitumen pitch of a solid system of cables, without showing any indication on the surface.

(7) *Climbing Poles.*—Inverted spikes placed round a pole will deter a native or mischievous boy, but does not prevent monkeys from swarming up and short circuiting the wires, and at the same time lowering the population of their tribe. Probably the only safeguard against these animals, is to wind barbed wire spirally round the pole for the whole length and solder it to the pole. Such barbed wire may also serve as an earth conductor for lightning arresters, more especially where barbed wires are run above the poles the whole length of the line.

Mr. Molesworth

The Cordite factory plant in India, alluded to in the paper, and with which I have been connected, obtains its power from a 600 feet effective waterfall, about four miles from the factory. The transmission is three-phase overhead, the voltage being 5,000 at a periodicity of 40 cycles per second. The whole plant, which I am glad to mention is of British manufacture, is now being erected under the superintendence of Mr. R. H. Molesworth, and on completion, particulars of the testing, trials, &c., will be published.

The author has treated transmission lines with special reference to the three-phase system, but I think the claims of single-phase transmission lines merit a place in view of future railway work, and also of its application to lighting as well as to combined power and lighting schemes. The success of the 20,000-volt 35-mile transmission line at Lausanne also illustrates the possibilities of continuous current transmission. In this latter, considerable ingenuity has been expended in the hydraulic as well as in the electric plant, and both as regards cost and convenience it compares very well with alternating current systems. The paper is a valuable collection of facts, and those of us who listened to it feel indebted to the author for his labour and for the excellent lantern slides shown.

Mr. Kemp

Mr. J. P. Kemp said—The utilisation of energy from water power has always been a fascinating problem for Engineers, and from the interesting information given by the author, it certainly appears that enterprising private companies are now giving the matter well merited attention.

It is, of course, well known that in this country high head falls are very scarce, and pioneers in water power enterprise have much opposition to face, both from the proprietors of the land and a section of the public whose only protest is "vandalism."

Cases have occurred in which the civil engineering costs of utilising the power of a low head stream have been so great as to militate against the financial success. The interest on capital and standing charges incidental to maintenance have outweighed the advantages of very low running costs.

I should be much interested to know if the author could give any information as to the running and total costs per K.W. hour for some of the water power schemes he has referred to.

With reference to the choice of a system of electrical transmission the "Star" combination appears to offer many advantages over the "Delta," and is certainly the most commonly used in this country.

The question of earthed or non-earthed neutral point on a three-

phase "Star" connected system is still a matter of controversy, and I cannot agree with the author that "the balance of evidence is in favour of the former." With the earthed system the insulation of underground cables may be considerably reduced, owing to the fact that the working voltage to which the cable is to be subjected is fixed, and cannot, as in the non-earthed system, increase $73\frac{1}{2}$ per cent. in the event of the outer being earthed. Mr. Kemp

With all systems, a point of first importance is safety to human life, and if in this respect any particular system offers an advantage, I consider that comparatively incidental expense should not militate against its adoption. The non-earthed system appears to offer this advantage, as I know of three authentic cases where men have, (through their bodies) accidentally earthed the outers of a supply at 6,000 volts, and although temporarily incapacitated by the condenser discharge of the main, they were immediately resuscitated, and are none the worse for their unpleasant experience. Had the men referred to been unfortunate enough to have fouled the outers of an earthed system at the same voltage, I believe I am safe in saying that nothing could have saved them.

With the earthed neutral point, a fault occurring on one of the outers invariably means temporary dislocation of a section of the supply, and, in some cases, a total interruption. In most cases this would be very inconvenient, and would weaken the faith of the consumers in the ability of the company to maintain a consistent supply.

The foregoing remarks apply, of course, to high tension systems only, and I am strongly inclined to the view, that for a large station supplying sub-stations which feed the town's network the non-earthed neutral system offers advantages which quite outweigh the comparatively minor, and purely financial, disadvantages of thicker insulation on the high tension mains.

In conclusion, I should like to thank the author for his valuable and interesting paper.

Mr. W. B. Esson said—Describing, as it does, several electric plants as actually installed, the paper does not give much scope for criticism, but it strikes me I might make one or two remarks upon the water wheels. Though the author compares the Pelton wheel with the turbine, apparently to the disadvantage of the latter, the cases in which they can be directly compared are few in number. The Pelton wheel and the turbine have each their own sphere of usefulness, and in the generality of cases no question arises as to which will give the best service under the particular Mr. Esson

Mr. Esson circumstances of the case, a fact which is often lost sight of in making comparisons.

To illustrate the point, compare two installations of the same magnitude, but having a different fall, one, for example, being one-fourth of the other. It may be assumed that a Pelton wheel serves most efficiently for the installation on the higher fall, but it is not clear that it would do so for the installation on the lower. When we come to the latter we have, in order to get the same power out of the wheel, to deliver to it four times the quantity of water. As the velocity of the water due to one-fourth of the fall would be a half, this means that we have to provide at the wheel eight times the area for the ingress of the water, and if the wheel has to run at the same speed, this means further that its diameter must be halved, so as to get, as in the case of the higher fall, the same relation between the peripheral speed of the buckets and the theoretical velocity of the water.

Now it may be found quite impossible to provide on a wheel half the diameter eight times the nozzle capacity, for nozzles cannot be stuck all round the wheel like quills on a porcupine. In such a case, when we have reached the limit of nozzles for the diameter, more wheels must be added on the shaft, and when this is done it will probably be found that a turbine would have been better and cheaper. The turbine is really a wheel with nozzles all round, but their shape is such as permits of their being packed close together and got into the space at disposal. The Pelton wheel is, on the other hand, an impulse turbine of the simplest form, and is, as the author says, particularly suited for high falls and small quantities of water.

The circular nozzle which has been characteristic of Peltons is, however, going out of fashion, and the latest and most scientifically designed wheels have rectangular nozzles. These admit of very much better governing than does the circular nozzle. With the latter, it has been attempted to regulate the flow of the water by means of coned spears inserted into and withdrawn from the nozzles, but governors operating tongues hinged in the rectangular nozzles are much more satisfactory. Buckets which split the stream of water impinging on them were known long before 1872—the date given by the author—and were in the Schiele Turbine in the sixties. I am sorry to think that as compared with the Continent and America the art of turbine construction is in this country far behind. The firms engaged in the industry do not seem to have made a comprehensive study of the principles involved, though it must be admitted in common

fairness that this not being a water power country, they have had but comparatively little practice. Mr. Esson

The installation at the Burma Ruby Mines presented a case where but for the peculiar character of the country, turbines would have been in the first instance employed. When the first instalment of plant was put in, the site of the power house was much nearer the source of water supply than now, so that the fall was only 60 feet instead of 200. The generators under the latter are directly coupled to the Peltons, but the first machine constituting the original installation was rope driven from a Pelton, which necessarily ran at a low speed. For 60 feet fall it seems somewhat absurd to have used a wheel of this kind, but the water is so charged with ruby grit that the buckets are practically being sand blasted all the time of working, and along with the nozzles want replacing every three months or so. With water of this character a turbine would be impossible, as guide blades, together with wheel buckets, would be rapidly worn out. However, as will be realised, the water supply here constitutes a very exceptional state of matters.

Mr. O. T. Domon said—The paper gives a very interesting summary of what has been done in this line in the United States and India, &c., and I quite agree with Mr. Scott's opinions and comments. Some information *re* the working of the Hochfelden Oerlikon high tension 30,000-volt transmission line, 14 miles long, may be of special interest, as the climatic conditions in Switzerland are more like the English than either the American or Indian climates. Mr. Domon

The Hochfelden Oerlikon line transmits 550 kilowatts average, the current being three-phase, and the periodicity 50. From 1892 to 1900 the working pressure was 15,000 volts, but from 1900 to the present date it has been 30,000. This doubling of the pressure has been made more for the purpose of investigating in practice the actual working of a high tension transmission line for industrial purposes than with the object of saving energy in decreasing the line losses.

The transmission line is composed of four wires (one being spare) disposed at the end of two cross-arms, forming a square of 50 (20 inches) each side. The diameter of the copper wire is 4 mm. (0·16 inches), and the resistance of a single conductor 31 ohms. Three different designs of insulators are used on the 260 poles of the line : some are of brown glazed earthenware, some white porcelain, some of the Delta type, 10 inches diameter.

Mr. Domon

The losses by radiation and leakage show the following average :—

At 20,000 volts	... ...	1 kilowatt
" 30,000 "	... ...	4 "
" 40,000 "	... ...	10 "

The weather and air conditions influence the losses as per following table :—

WORKING PRESSURE 30,000 VOLTS.

Clear sky—dry	0·9 kilowatts
" " after night frost	1·8 "
Dry snow—temperature below freezing point...	2·2 "
Overcast—a couple of hours after light rain ...	3·0 "
Wet snow—thawing	4·9 "

The above table shows that the losses are mainly due to leakage, and, as the author remarks, can be reduced by using a better class of insulator.

The leading current component averages 1·25 amperes.

The transmission line was formerly protected against atmospheric discharges by means of lightning conductors on every pole, but during the first year of working at 30,000 volts (1900-1901) several poles became charred. This led to the replacing of all these conductors by means of three lightning arrester sets (Siemens-Halske horn type) one at each end, and one in the middle of the line. The air gap of these arresters is 55 mm. (2·2 inch). Since that time no pole has been charred, and the transformers and alternators have never been damaged, although the line has been struck by lightning about 50 times every year.

One effect, however, has sometimes resulted from the striking of the line by lightning, namely, in a few cases the low tension synchronous motors running in the secondary station at the Oerlikon works as phase rectifiers, have fallen out of step.

The signalling telephone line with two wires is run on the same poles about 1·5 mm. (5 feet) below the lowest transmission line. The telephone line is transposed at 20 places, and although the humming of the alternating current is perceptible, conversation can easily be held. Any important leakage in the transmission or the telephone line will set the telephone bell ringing in consequence of the disturbance of the electrostatic equilibrium in the lines.

According to the last statistical tables (1902) of the Swiss Institution of Electrical Engineers, the total capacity of the turbines and water wheels driving electric generators for power supply concerns in Switzerland (exclusive of all the private plants and

emergency steam or gas motors) amounts to 132,650 B.H.P. The Geneva Corporation heads the list of 95 concerns with 19,000 B.H.P. Mr. Domon

Mr. Noel Humphreys said—As interested in the development of Water Powers, especially in North Wales, the author's exhaustive paper specially appealed to me. It is on the general and commercial side rather than the engineering side that I approach the matter. Mr. Humphreys

The industrial development of this country, as well as of other countries, has been so bound up with the application of steam that even the new era of electrical possibilities is thought of as attainable only through the old gate of wasteful fuel combustion. The coming dominant race of scientific engineers (of whom H. G. Wells has given us so many startling and pregnant "anticipations") will, however, advance from the present non-economical methods of creating and employing energy to some simple and effective means of liberating, controlling and directing natural forces for all the material work of the world.

It is a step towards such an emancipation of the engineer from the bondage of coal-fed machines to find him harnessing water powers. Naturally, the largest strides have been made out of Great Britain and in those countries where the absence of coal and the presence of water-falls joined in an insistent duet.

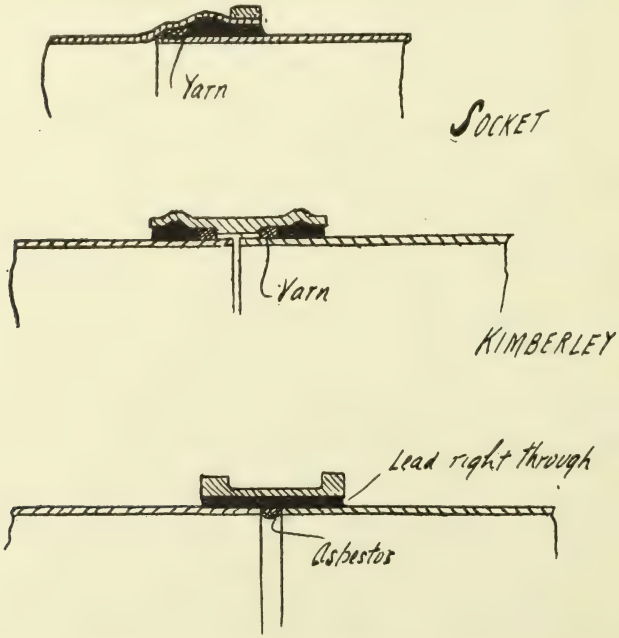
We are slow in this country to learn from foreign or colonial experience, and are rather prone at times to depreciate what we possess at home. When we do wake up, however, we can turn it to full advantage, and this is what is happening now in North Wales. Here is a country rich in mineral wealth, much of it comparatively remote from its coalfields and inaccessible by steam railways. On the other hand, in the Snowdon district it possesses a rainfall of unique volume, with natural advantages for storage at high elevation. The factors for the utilization of the natural forces to commercial profit have always been there, but there they have remained unnoticed until the men to combine them have also appeared. And not merely to commercial profit but to national advantage. For surely, if that man is a benefactor who makes two blades of grass to grow where now but one struggles, they are no less deserving of encouragement who harness the forces of nature and employ in assisting the manifold activities of commerce what otherwise would pass away unused. Instead of contributing to the depletion and ultimate exhaustion of the coal beds that cannot be replaced, and which in a sense is drawing

Mr. Humphreys upon capital, the utilization of water power is the reaping of a perpetually renewed harvest that will remain as bountiful to our successors.

The possibilities of successful commercial development of water-generated electricity from Snowdon district and from the Conway Valley are varied. In quarries and mines, in factories and workshops, for traction over the network of electric railways that will in time open up the picturesque fastnesses of the country to that larger number to whom coach driving is a prohibited luxury—in all these ways they open up wide fields and a great future.

And presently the cheap and plentiful supply of electric energy will stimulate the development of other industries. Perhaps a wonderful revival of village industries in which the small electric motor operated at home may be a safeguard and a solvent against the aggregation of the workers into dense centres. So is it permitted to the engineer to influence his country and his time.

Mr. Scott Mr. E. Kilburn Scott, in reply, said—Regarding Mr. Haarer's query *re* lead joints for high pressure pipes, it is, of course, necessary to provide some means of preventing the lead being forced out, and the author shows several of these in the figure herewith. At Snowdon,



for a head of 1,150 feet giving a pressure of 500 pounds per square inch at the bottom end, a lead socket joint is employed. Mr. Scott

One great advantage of such lead joints is that it allows the pipes to follow slight unevenness in the ground without having to make special bends. On the Snowdon pipe line, for example, most of the curves are 600 feet radius, and all the pipes are in straight lengths. In the very few places where the pipe does change direction short curved cast-steel anchor joints are provided.

One point in connection with keeping joints tight is that it is well to have the collar or socket perfectly circular. In a welded pipe this is so, and in a rivetted pipe the edge of the over-lapping plate can be pared down at the joint to give practically a circular section. The locking bar pipe, on the other hand, as usually made, requires two raised places in the joint ring where it passes over the locking bars. An improvement due to Mechan & Son is to depress the edges of the plates so as to bring the outside of the locking bar flush with the outside of the pipe.

In laying a pipe line everything depends on the caulking, and the best practice is to do this in at least two stages. On the Coolgardie line, machine caulking was tried, but hand caulking is undoubtedly best, as the man can feel just how the lead is going. A machine cannot take cognisance of this.

Regarding the clearing out of long water pipes, there is a most ingenious machine for this, and which, the author believes was first used on the water supply pipe from North Wales to Liverpool. It consists of a whale-bone brush which is rotated by the flow of the water through the pipe.

These growths are usually formed where the water passes over peaty soil. If the water is taken direct from a mountain lake at a high altitude, as at Snowdon or from a glacial stream in Switzerland and the Western States, &c., there are no growths in the pipe. Of course, if one adopts rivetted piping it is just as well to allow a little extra diameter to provide for the obstruction of the rivet heads, and anything which may lodge against them.

Mr. Haarer's statement as to high pressure Pelton wheels not costing a single penny for repairs or renewals in 4½ years' running goes to show what an extraordinarily simple prime mover the tangential wheel is.

One feature of the wheel is that its material parts—that is: the buckets, nozzles and governor—can be supplied by a specialist firm, and the heavy castings, casings, &c., made by some local firm. For work

Mr. Scott abroad it is thus possible to make a large saving in freight and yet be certain that the completed wheel will give the desired result. It would be dangerous to attempt this with any other type of prime mover.

Mr. A. H. Robinson refers to troubles with the tail race water, as experienced by the San Joaquin Electric Co., but this has been obviated by the use of renewable slabs of cast-iron. The Company was one of the pioneers in Power Transmission, and has been a great success, both technically and financially.

It may be of interest to mention that Mr. J. E. Rawlins, of Bristol, who is chairman of the North Wales Power and Traction Co., is also chairman of the Hanford Waterworks, which is one of the largest customers for power of the San Joaquin Electric Co., the total distance to Hanford being 70 miles.

Mr. J. E. Rawlins, writes as follows :—

"Some six years ago we extended the pole line from Fresno (the "headquarters of the Company) to Hanford a distance of 35 miles, "on the understanding that all monies falling due for power should be "applied against the cost of building this line with interest thereon, "when the line would belong to the Company. This was accomplished "about a year ago, and having received our money back, we are now "paying the Company for our power. The arrangement has worked "admirably, and with the exception of the first year, when there was "a temporary shortage of water, we have never had any trouble or "interruption of service."

The difficulty of frost is obviated in two ways, first by burying the pipes with earth and turfs as much as possible, and the second by allowing a certain amount of water to always flow through the pipe at times of very low temperature. The pipe line from Lake Glaslyn down to the Copper Mill on Llydaw has been in position many years, and has never been frozen, although it is not protected in any way.

In any case, large pipes of several feet diameter are, of course, not so liable to freeze up as are pipes of a few inches in diameter. That is one reason possibly why one never hears of the pipe lines in Scandinavia, Switzerland, &c., freezing up.

Mr. Molesworth's contribution is of great interest, particularly where he draws attention to the special conditions which have to be met in tropical countries, &c. His Continental experience and connection with the transmission of power for the Government Cordite Factory in India enables him to speak with assurance on the question of lightning, and it is interesting to hear that arresters as at present used quite meet the requirements.

Mr. Molesworth mentions dust storms as a serious difficulty; they are more so than snow, for when dust penetrates anything it stays there, whereas snow melts away. A partial short circuit from snow may cause a flow of current, and this local heat by melting the snow rectifies the fault. With dust this is not so. However, even dust troubles may be overcome, as is shown by successful installations in South Africa and other places where dust storms are frequent. It is after all only a matter of giving additional space between the wires and additional surface on the insulators. Mr. Scott

Regarding white ants, this difficulty is met by using metal poles or where the tension is extra high by means of wooden poles with metal bases. By filling the inside of the metal base with cement the ants cannot crawl up inside and so get at the wood, and, of course, they never think of crawling on the outside of anything.

It may be mentioned that if a wooden pole does collapse unexpectedly from any cause it is not likely to pull down the wire, as the binding wire or the insulator or cross-arm bolt would give way first.

Regarding single-phase and continuous current, for transmission of power, the author believes single-phase to be quite played out, and where the latter has met with any success it is more in the nature of a freak installation, and not applicable in general practice.

As Mr. J. P. Kemp points out, the large civil engineering costs of a low head stream must militate against its financial success. Personally, the author would not consider any fall unless it was at least some hundreds of feet high, and had a natural lake to feed it. Such a conjunction of circumstances are very rare in this country, indeed the author does not know of any other except on Snowdon and Lake Eigau, in the Conway Valley, but abroad and in the Colonies the condition is common enough, much more so than stay-at-home engineers seem to be aware of.

Mr. Kemp's remarks on the question of earthing are instructive. In three-phase railway work, such as at Burdorf-Thun, and Vattellina, and as is proposed for the narrow gauge railways in North Wales, one of the phase lines must of necessity be earthed. Such earthing does, undoubtedly, simplify the system, but at the same time it tends to unbalancing and may disturb the telephone and telegraph services.

Mr. W. B. Esson's description of a turbine as being a tangential wheel with the nozzles packed close together is novel, but hardly correct, for the tangential wheel works entirely by impulse. Some

Mr. Scott tangential wheels have been made with the nozzles above and below, but as a matter of fact, given sufficient pressure, almost any power can be obtained from a single nozzle.

The Abner Doble Company, for example, have supplied two wheels for the Nimshaw Plant of the California Gas and Electric Corporation which gives 3,700 H.P. each, under 1,531 feet head, also one to develop 7,500 H.P. Each of these wheels has only a single nozzle.

It may be of interest to mention that the shaft carrying the revolving magnet wheel of the generator, is a hollow forging of $3\frac{1}{2}$ per cent. nickel steel, oil tempered, and a large flange forged solid on to the end of the shaft forms the hub of the water-wheel. The wheel is a forged steel disc 10 feet 5 inches in diameter, weighing $4\frac{1}{2}$ tons (machine), whilst the buckets are open hearth steel castings. As exact balance is a very necessary feature of high speed wheels the buckets are machine finished, and reamed to a jig, so as to be strictly interchangeable and of exact weight.

Interchangability of the buckets is a great point, because, as Mr. Esson points out, some water is so full of grit, &c., that the buckets are being sand blasted all the time. Buckets are usually made with a factor of safety of ten to one, the most severe condition that can exist being when the wheel is standing and the jet suddenly impinges on to a single bucket.

Regarding the question of efficiency, it may be useful to give some figures. Experiments conducted at the Massachusetts Institute of Technology, by Professor Porter, showed the efficiency of a nozzle made by the Abner Doble Co., to be for one-quarter opening $97\frac{1}{2}$ per cent., and for 25 per cent. overload 99 per cent. In some preliminary tests conducted by Professor L. M. Hoskins, of Stanford University, the combined efficiency of water-wheel and nozzle at one-third load was over 80 per cent., and at a maximum load over 84 per cent. In some tests in Southern California, conducted by Mr. F. E. Trask, at the plant of the San Antonia Co., the efficiency of the tangential wheel after the plant had been in service for over six months was 83·34 per cent.

The author is much indebted to Mr. O. T. Domon for the particulars which he gives of the 30,000-volt Hochfelden Oerlikon transmission. When one hears that this line is struck by lightning on the average of 50 times a year, and yet gives no trouble, it will be seen how little there is to fear from such overhead lines in this country.

The variation of losses according to the weather, shows that even with the wires so close together as 20 inches the losses are quite trifling, being less than one per cent. even for wet snow thawing. Mr. Scott

Mr. Noel Humphrey sees the matter from the point of view of the interested layman, and what especially appeals to him is the fact that utilising a water power differs from consuming coal in that it does not exhaust our natural resources.

There is no doubt that this generation is exceedingly wasteful of coal, and we are in a sense living on capital.

When it is considered that of the potential energy of coal averaging 13,500 British Thermal Units per pound only about 1,200 units is delivered on the engine shaft, it will be seen how extremely wasteful it is compared with the utilization of falling water.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

NINTH MEETING—24TH FEBRUARY, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. W. P. JONES, J. F. MACNAB, and E. A. ROSENHEIM, as *Members;* and Mr. HOWARD E. MARTIN, as an *Associate.*

SURFACE CONTACT AND CONDUIT TRAMWAYS.

BY GEORGE BALFOUR, M.I.E.E., A.M.I. Mech. E.

IT is the author's object to discuss the methods of conveying electricity to electrically propelled tram cars by systems other than the overhead trolley system. This really means that we are confined to a criticism of two systems, known as the "surface contact" and the "conduit." It is unnecessary to include any other system, as up to the present there has been no system in practical and successful operation except the above named.

It is not proposed to enter into a lengthy historical outline of either system, as to do so would alone take up a greater time than we have placed at our disposal.

The author proposes to proceed as follows :—

(1) Very briefly describe two or three surface contact systems in

actual operation, and select one as a basis for comparison with a conduit system.

(2) To more fully describe the particular surface contact system selected as above mentioned.

(3) To briefly outline one or two conduit systems in operation and select one as a basis for comparison with a surface contact system.

(4) To more fully describe the particular conduit system selected as above mentioned.

(5) To compare the cost of the system, both as to capital and operating.

At the outset, it may be mentioned that what is known as the surface contact system is, as probably you are aware, a system in which the electricity from underground feeders is conveyed to the motors on the tram car by means of metal studs or plates placed at fixed distances along the centre of the tramway track, these studs being electrically connected to the cables when the car passes over them, the studs being dead before the car reaches them, and after the car has left them.

The conduit system may be generally described as a system in which the electrical conductors contained in an open culvert are directly connected to the feeding cables, the electricity being conducted to the motors from the conducting bars through a plough, which is connected to the underside of the car and makes connection with conducting bars through an open slot in the roadway.

Among the surface contact systems in actual operation the following may be mentioned :—

(1) Claret—In operation in Paris.

(2) Schukart—In operation in Munich.

(3) Dolter—In operation in Paris.

(4) Diatto—In operation in Paris.

(5) Lorain—In operation in Wolverhampton.

The foregoing system may be divided into two classes, viz. :—

(*a*) The sectional class, in which the studs are controlled by a switch gear in sections. The first system named may be included in this section.

(*b*) The separate class, in which each stud is electrically controlled independently of any other stud on the system. The systems numbered 3, 4 and 5 are included in this class.

On the systems in class *a* the studs consist of a plain metal block, fixed in the roadway between the rails of the tramway track. Cables are laid in groups, each cable of the group terminating at one end by

a connection with one of the metal blocks, and at the other end by a connection to a switching device fixed in a chamber under the side-walk. About 20 studs are connected to one of the switching devices, so that when a car is on one section of studs the next following car must wait until the car on that section has moved forward to the next section ahead, as the switch mechanism can only be used for electrically connecting the studs to one car at a time on that section. The objection to this system is obvious, as a certain distance varying from a few feet up to the total length of one section must always be kept between any two cars. This alone makes the traffic very awkward to handle, the objection becoming greater as the headway between the cars is reduced. The principle on which this system is based is therefore only suited for application in places where a very light service of cars is run, but even in such places two cars would frequently run on to one section. The last car to run on to the section would of course be at a standstill.

It is impossible to describe all the systems in detail, and the author does not think that any good purpose would be served in so doing, but, in order to give a general idea of the system, he has given the following illustrations :—

Fig. (1) Claret system—switching device.

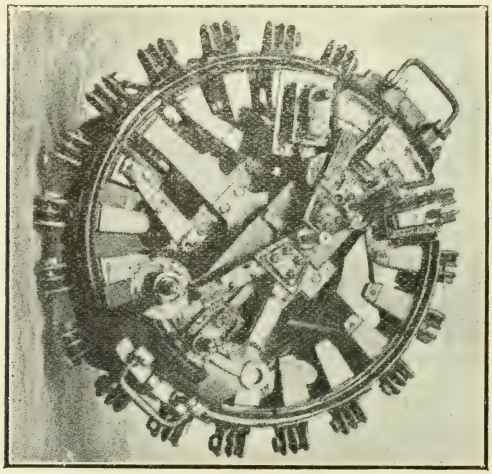


Fig. 1.

Fig. (2) Claret system—diagram of connections.

At the end of this paper the author has given a brief note showing the general functions of the various parts. He has followed this course

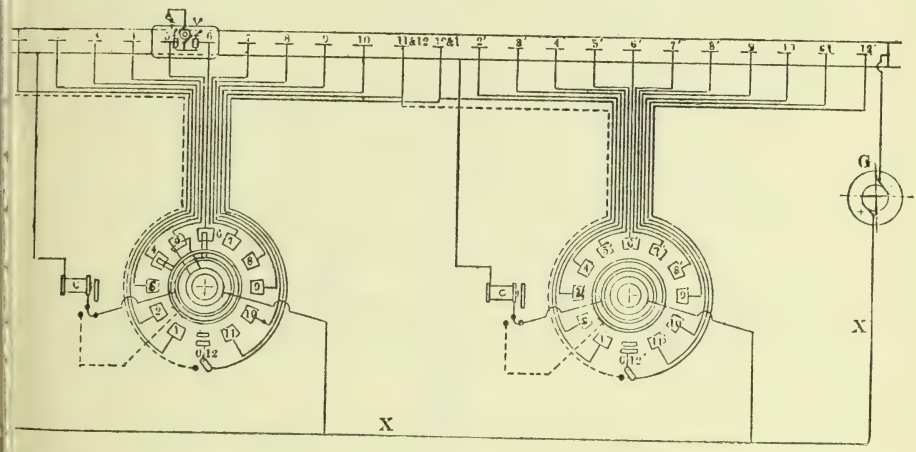


Fig. 2.

so that you may have an intelligent idea of the details of these systems without making the paper unduly long or tiresome.

The Schukart system does not come under this class, but is similar in so much as it has a contact stud consisting of a plain metal block, the switching device being placed under the sidewalk or road, each switching box controlling a number of studs. The Schukart system has, however, the great advantage that it is not sectionalised, and therefore really belongs to the class next described. The arrangement is exceedingly good. Having overcome the sectional difficulty there is a great deal to be said for placing the switch gear in accessible boxes open to inspection while cars are passing.

The Schukart system has been in operation in Munich since 1896, and was fitted with the improved apparatus as now used by the Schukart Company, in 1899, since which time the author understands the operation of the system has been satisfactory.

The last three systems (class *b*) are similar to each other, and different from the first one (class *a*), in so far as immediately under each metal stud is a switching device for electrically connecting the stud to the cables, so that the cars can follow close upon one another, as the magnets on each car operate the switch mechanism under the studs immediately under the car, contact to each being made

independently. It will be seen, therefore, that the principle on which the Dolter, Diatto and Lorain systems are constructed is better suited for the conditions obtaining in most towns than the Claret.

Two illustrations of the Dolter system are given, which are sufficiently clear to indicate the general arrangement, and to allow of a comparison with the other systems.

Fig. (3) Diagram.

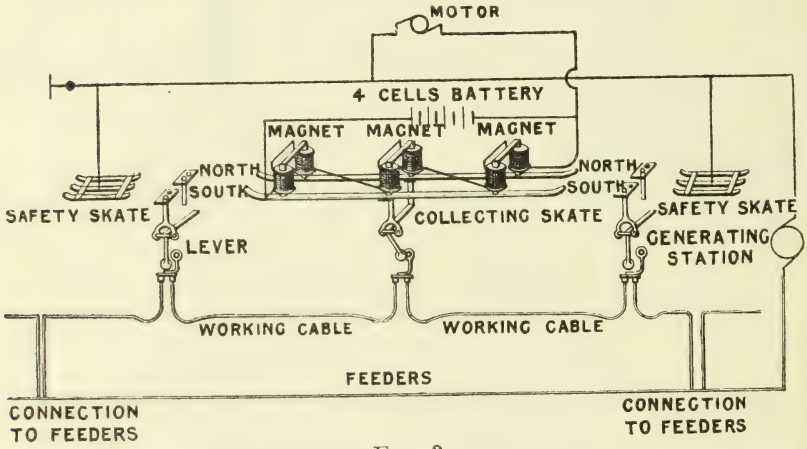


FIG. 3.

Fig. (4) Cross-section of Dolter stud and road bed.

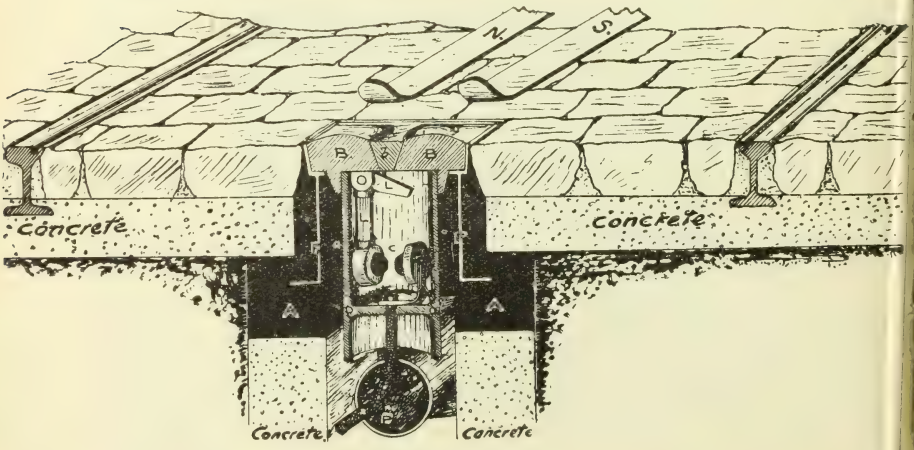


FIG. 4.

The Diatto and Lorain systems have been purposely left to be dealt with together, as in the author's opinion the Lorain system is, to a large extent, the Diatto system with certain important modifications and improvements. The Diatto system is generally illustrated in Figs. 5, 6 and 7.

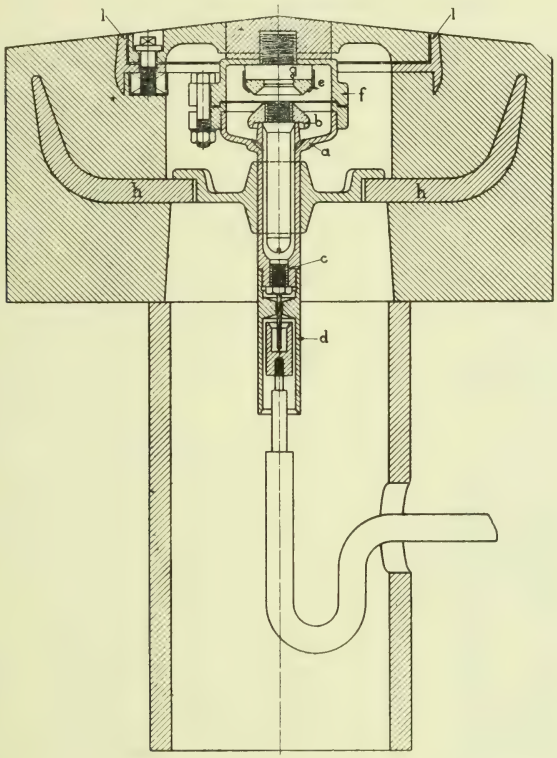


FIG. 5.
Diatto Mechanism Stud and Asphalt Block.

In this (the Diatto) system it will be seen that the metal stud forms the cover of a box in the roadway, containing the switching device. On the underside of this metal stud, and attached to it, is a cup made of insulating material. The lower end of this cup carries a cylindrical tube, which projects downwards into the duct containing the feeder cable. In the top of the cup, and immediately under the metal block, is screwed a metal plug containing, on the underside, a carbon disc. The cylindrical portion in the bottom of the cup carries a plunger floating in mercury, the top of the plunger being capped

with a carbon disc, this disc being immediately below and separated from the upper disc. It is unnecessary to describe the Diatto system further, as it will be clearly understood on referring to the illustrations after the description of the Lorain system, the difference in the two systems being mainly in detail construction, and the substitution of a sheet copper connection for mercury.

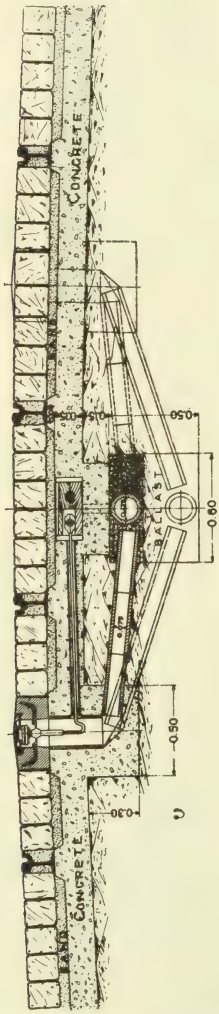


FIG. 6

Shewing Studs, Cables and Drainage.

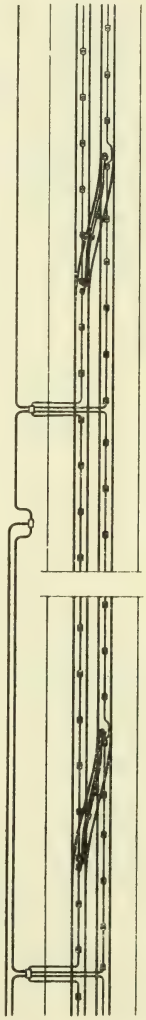


FIG. 7.

Improved System of Distribution of Feeders.

The author will therefore not enter further into the details of the Diatto system, but will take up the Lorain system and go through the full detailed construction.

Of all the foregoing systems the author thinks it will best serve the present purpose to take the Lorain system for comparison with the conduit system, because it is actually working under British climatic and traffic conditions, and has been working a sufficiently long time to enable an opinion to be formed as to the value of the line; also because data is available for comparing the capital and cost of operating and maintenance with the conduit system.

The Lorain system at Wolverhampton is the only surface contact system in operation in Great Britain at the present moment beyond the experimental stage. The line consists of about 11 miles of single track, on which 22 cars are being operated.

The arrangement so far as the general appearance is concerned is that common to all surface contact systems, viz., studs placed along the centre of the track, which are electrically connected to the cables by the operation of a contact switch placed inside the chamber under the stud. The studs are spaced about every ten feet throughout the track on the straight but at a lesser distance on curves and for special work.

The description of the system may be divided as follows :—

Contact box.

Magnets and collector gear.

Cable layout.

The contact box in any system of surface contact tramways is necessarily a vital part, and therefore worthy of careful consideration.

The box consists of a rectangular block of insulating material called reconstructed granite, hollowed out so as to leave a sufficient space to contain the insulating cup carrying the switch or contact mechanism. The block measures $16\frac{1}{4}$ inches by $10\frac{1}{4}$ inches by $7\frac{1}{2}$ inches outside. The top of the reconstructed granite block is recessed so as to receive a metal cover 15 inches in length by $9\frac{3}{4}$ inches wide. This cover is fixed into the recess in the top of the block and held into position by two bolts passing through the block, the heads of the bolts being sealed in recesses in the underside of the block. The metallic cover which forms the stud is built up in three pieces, the outer piece being of iron, the first inset piece being also of iron, and the centre inset piece (which is the part subject to the wear of the collector gear) being of special non-magnetic steel. The centre of this cover when the track is finished is about $\frac{3}{4}$-inch above the surrounding paving.

The lower portion of the granite block or casing carries the cylindrical cast iron socket which passes into the casting brought up from the cable trough immediately under the grantite block.

The granite block with the cover and fitting described completes the chamber for carrying the contact or switch mechanism.

The contact or switch mechanism is of the simplest description, and is contained in a hollow insulating cup made in two sections. This cup does not fit close into the granite block but is separated by a space of about $\frac{3}{8}$-inch from it. The space is filled with a special oil which is heavier than water, consequently all water rises to the top.

In the top and bottom sections of the cup brass terminals are moulded into the insulating material of which the cup is formed. The terminal in the top section is screwed into the underside of the metal contact plate, and serves to make electrical contact with the top plate, and also to support the cup.

The brass terminal in the bottom section is a spring contact used for connecting the movable switch contact to the cable terminal, which is carried by the cast iron cylinder fitted into the granite block already referred to.

The contact mechanism consists of an armature of a thin sheet of soft iron, $4\frac{3}{4}$ inches long by 2 inches wide by $\frac{1}{16}$-inch thick, with a carbon contact disc fitted in the centre to the upper surface. This armature when not in use lies on a circular ledge in the bottom of the cup. When making contact the armature is drawn upwards by the magnetic pull exerted by the magnet carried by the car when the car passes over the stud. The armature of soft iron is connected to the terminal in the bottom of the cup, and consequently to the supply cable, by a piece of hard rolled copper strip $1\frac{1}{2}$-inch wide, folded so as to form a double flap. This arrangement permits of free vertical motion with scarcely any frictional resistance, and at the same time the strip being flat the armature with the carbon disc attached is free to fall by gravity into position in the bottom of the cup without any further guide than that afforded by the formation of the strip.

The circuit is closed every time the car passes a stud by the armature being pulled upwards, consequently bringing the lower carbon disc which is fitted to the top of the armature into contact with the carbon disc fitted to the underside of the metal stud or cover. The current passes from the underground cable through the lower terminal, rolled copper strip, carbon discs, on to the metal road stud, from which contact is made by the collector (which will be described later), carried underneath the car. From the collector connections are made in the usual manner to the controller and motor.

Fig. 8 shows clearly the details of the Lorain Surface Contact Box and Switch Mechanism.

The magnet used for operating the contact mechanism and the collector to carry the current from the studs to the motors are the next important considerations.

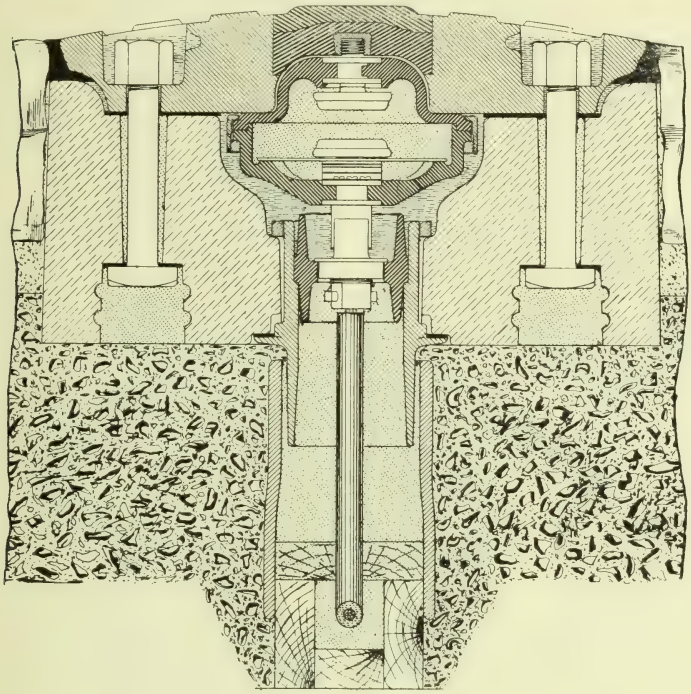


Fig. 8.

The magnets consist of six-electro magnets, having the ends of the yokes connected by iron plates, so that the two iron plates form two long magnetic poles. The general arrangement of the magnets can be understood readily by reference to Figure 9, the magnets being shown in position over the stud.

The magnetic path is through the core of the magnet, below the magnet and stud, through the stud and space below to the armature. The armature is thus raised as already stated and completes the electrical circuit to the stud. As soon as the magnet has passed over the stud the armature falls by gravity and breaks the circuit.

The winding of the magnet coils is compound, one coil being in series with motors and the others being a shunt winding for 500 volts. It follows that with heavy loads when the E.M.F. has dropped, the

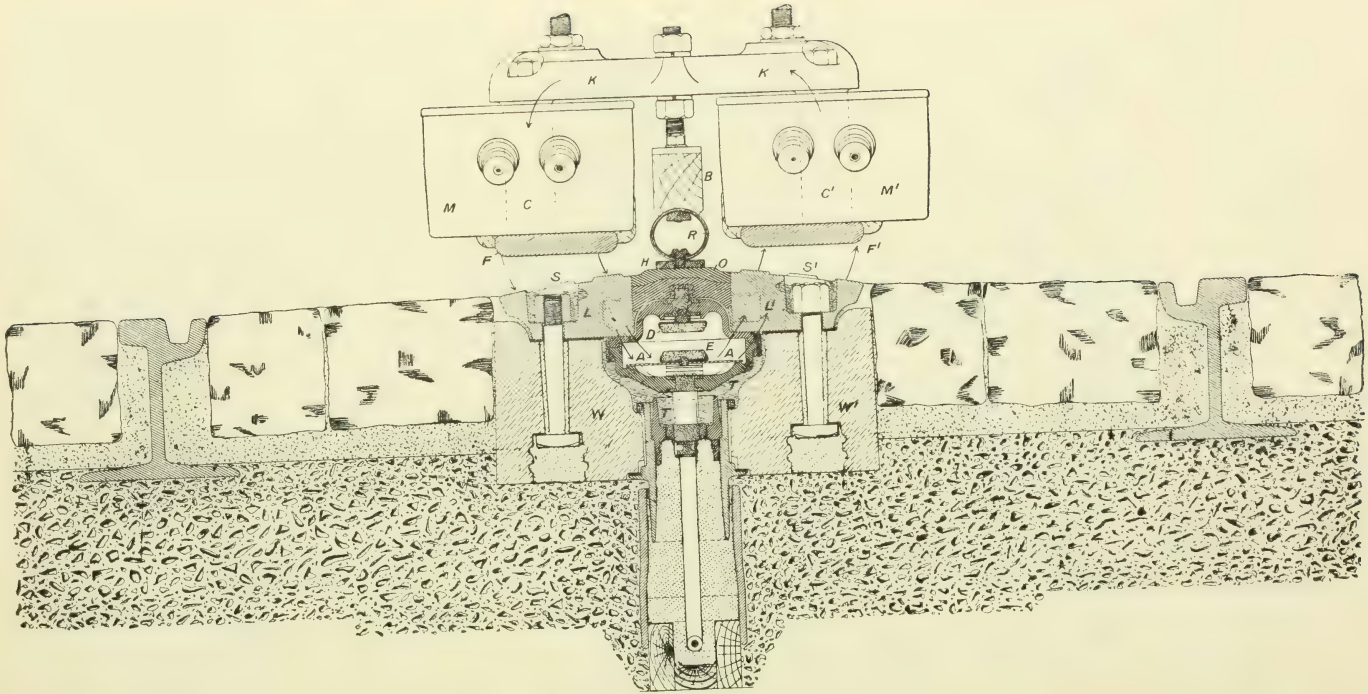


Fig. 9.

series coils increase the excitation owing to the excess current passing. This ensures that the requisite magnetic pull is maintained, or even in cases where a large current is passing into the motors in consequence of increased load the magnetic pull is increased owing to the larger current circulating the series coils of the magnets.

In the car sheds, to excite the magnets to start the car a small accumulator battery of eight cells is used, and this battery is also used in cases of emergency.

The collector gear consists of a stout bar of hard wood fixed between the magnet poles and carrying on the underside a piece of canvas covered hose fixed as shown on the illustration, Fig. 9. To the bottom of the hose a flat strip of tough brass is fixed and extends the whole length of the bar, the ends projecting over the bar at each end, and being turned up so as not to catch any obstacles. The magnets and collectors weigh about one ton. The collector has proved efficient and economical.

The system of cables is simple and scarcely requires description. Feeders are laid to feeder pillars in the usual manner, and the distribution to the contact boxes is as shown on Fig. 10. Further remarks on the whole system will be made towards the close of the paper.

Among the various conduit systems may be mentioned the following :—

Blackpool, centre slot.

Buda-Pesth, side slot.

Paris, side slot.

London County Council, centre slot.

Bournemouth, side slot.

There are numerous other conduit systems at work in America and on the Continent, but no good purpose would be served by the naming of these various systems, as the selection given above will satisfactorily review the position which conduit tramways occupy.

It may be considered somewhat singular that the author should have included in the above list the Blackpool conduit, which, as you are no doubt aware, was taken up and replaced by overhead trolley some years ago. He mentions it simply to call your attention to the time that it is about 20 years since the first attempt was made in England to establish an electric conduit tramway, and also to show the marked difference between the construction of this conduit and the construction of the only conduit systems in England to-day; the oldest of the existing conduit lines in this country being about

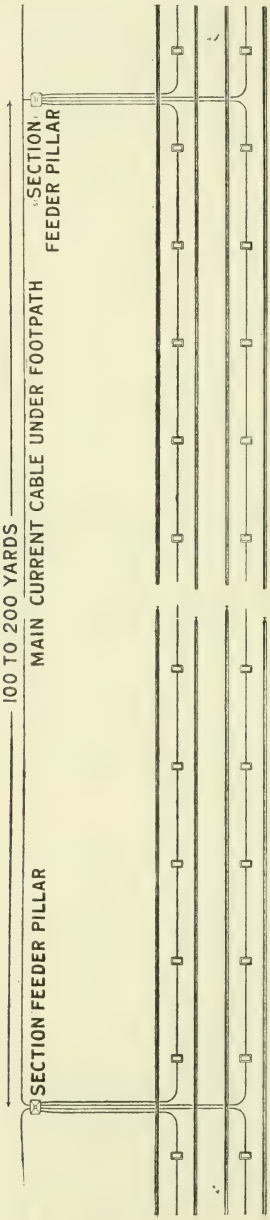

100 TO 200 YARDS
SECTION FEEDER PILLAR
MAIN CURRENT CABLE UNDER FOOTPATH
SECTION FEEDER PILLAR

FIG. 10.

15 months. The old Blackpool conduit was designed and constructed by Mr. Holroyd Smith, and weak as the construction was, no doubt it would have achieved a greater measure of success had it been laid in an inland town instead of a town so exposed to sand storms as Blackpool. The illustration given (Fig. 11) indicates the type of

Transverse Section of Conduit, Blackpool Electric Tramway.

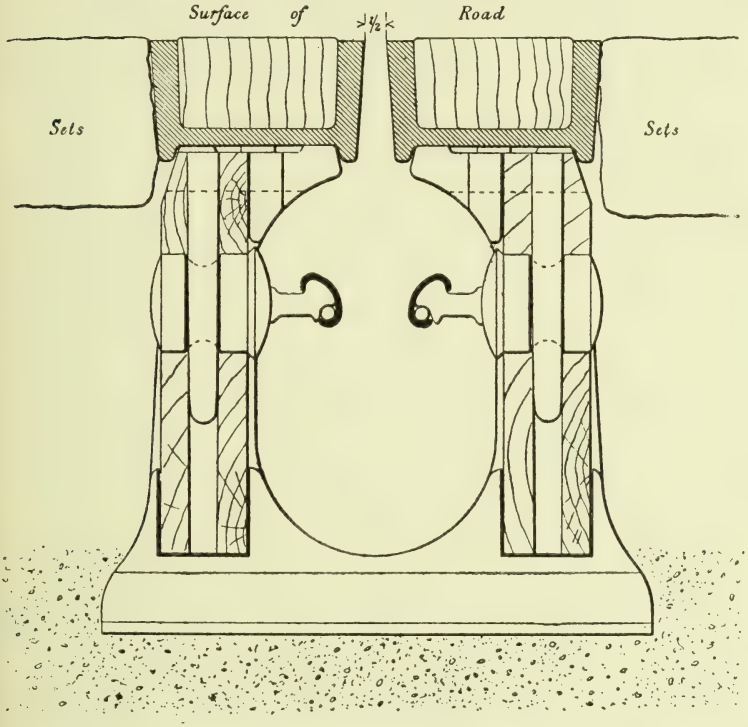


Fig. 11.

construction. The conductors consisted of two curved copper conductors fixed to insulators carried by iron chairs; the two conductors were connected in parallel so as to be in effect one conductor only; the return connection was made by the rails.

Buda-Pesth was the first continental city to adopt the conduit system. The system was designed and constructed by Messrs. Siemens & Halske, and opened for traffic in 1889. This was one of the first slide-slot systems in the world, and was certainly a well constructed line for the time it was constructed, but the author is

afraid that no British Corporation would have allowed any Company to lay down a similar system in this country, as the slot opening varied from $1\frac{1}{2}$ inches to $2\frac{1}{4}$ inches.

The rails were not used for a return, the double conductor bar being fitted in the conduit.

Regarding the Paris conduit system, it is not necessary to enter into any detail, as this will all be covered by the description of the Bournemouth tramways, the systems being practically identical. It is worthy of note, however, that for a number of years over 20 miles of conduit tramways have been running in Paris, on which over 150 cars are operated.

The London County Council Tramways are no doubt attracting considerable attention at the moment, and, for that reason, the author gives an illustration (Fig. 14, Plate I) showing a cross section of the road through the conduit; this, after the description of the Bournemouth tramways is given, will be quite clear and will not require any further description. It is generally known that there is already in operation, or ready for operation, about 40 miles of centre slot conduit tramways in London, and the only trouble that has arisen has been due to a batch of defective collectors or ploughs, but this, of course, is a detail which in no way indicates a weakness in principle, and is readily remedied. Fig. 16 shows the conductor rail and slot rail section.

The author has left the Bournemouth conduit for a full description, as he thinks it may be truly said that it embraces all the features of a successful conduit tramway, and is built according to the most modern practice. The Bournemouth conduit tramways also are particularly suitable for comparison with the surface contact system described, owing to the fact that the Bournemouth tramways are being operated under British climatic conditions, and have been in operation a sufficiently long time to prove their reliability, and to show that the cost of operating compares well with other systems of electric tramways.

The author should have preferred to have had a system with conduit tramways only at work, without the combination with the trolley, as he is not at present able to obtain separate costs to satisfactorily compare the systems.

The installation at Bournemouth consists of about three miles of conduit construction and 17 miles of overhead trolley construction, an interesting feature being that all of the cars work over both systems, being mounted with collector gear for conduit and overhead. The

author is only to deal with the conduit part of the tramway, as the trolley road does not enter into this paper.

He does not propose to enter into the question of combined systems of overhead and conduit tramways, but thinks it will be an advantage that the conduit described should contain reference to the method adopted for changing over from the conduit to the overhead system, as this may appear to you to be a difficult matter, and, at the same time, a very necessary one.

The Bournemouth system is almost identical with the Paris system, as indeed is only to be expected, seeing that both systems were constructed under the supervision of the same Engineer, Mr. A. N. Connett. In the Bournemouth system, the two conduits are placed under two inner rails where double track is used. These rails, under which the conduit is placed, are of a special section, and designed so as to form both slot and wheel rail. It has been argued that the one great objection to a conduit system is the fact that you must have a slot on the road surface, but in the side slot system which we have under consideration, the slot occupies the position usually occupied by the groove in the rail for the flange of the wheel. The slot must therefore be not less than one inch wide, as this is the minimum width which can be used for the wheel flanges. So far as the slot opening necessary for the collecting gear is concerned it need only be $\frac{3}{4}$-inch.

The slot rails are supported by yokes spaced 3 feet 9 inches apart, and these rails are bolted through the bottom flanges to the slot rail seats. The yokes are of cast iron, and are arranged with lugs to accommodate tie-bars for the purpose of tying the slot rails back to the yokes. The slot rail, which is also used as the wheel rail, is also tied to the outer wheel rail with tie-bars spaced 7 feet 6 inches apart. The general arrangement of slot rails, yokes and tie-bars, will be seen from the illustration. (See Fig. 12, Plate I.) The formation of the conduit tube is also seen from the same illustration, the depth from the bottom of the tube to the rail surface being 2 feet $0\frac{1}{2}$ inch, and a width of 14 inches. It will be seen that the yokes are embedded in 9 inches of concrete, the tube between the yokes being formed of concrete 6 inches thick. In the tube thus formed the conductor bars are placed for supplying electricity to the cars. In this connection it is worthy of note that two conductor bars are employed, one for the positive and the other for the negative; therefore, there is no earth return, and consequently no necessity for bonding the track.

The insulator and cast iron fixtures for fixing the insulator to the slot rail and conductor bar is clearly illustrated in Fig. 13, Plate I. It will

be seen that a massive casting in the shape of an inverted cup with a projecting lug is used, the cup being corrugated on the inside. Into this cup is cemented a porcelain insulator carrying a bolt which in turn carries a flat plate which is bolted to the conductor bar. The design of details of the insulator and fixtures will be clearly gathered from the sectional drawing, Fig. 13, Plate I. It is perhaps worth mentioning the arrangement used for adjusting the conductor bars after being placed in position. The arrangement is exceedingly simple, and at the same time very effective. The flat plate to which the insulator bolt is connected carries on its upper surface a washer having the hole eccentrically placed. This washer lies on the plate and is bound in the transverse direction of the conduit by two lugs. It will be seen that by turning the washer the conductor bar is readily moved to and from the centre of the slot transversely across the conduit, thus permitting a ready adjustment of the space between the two conductor bars.

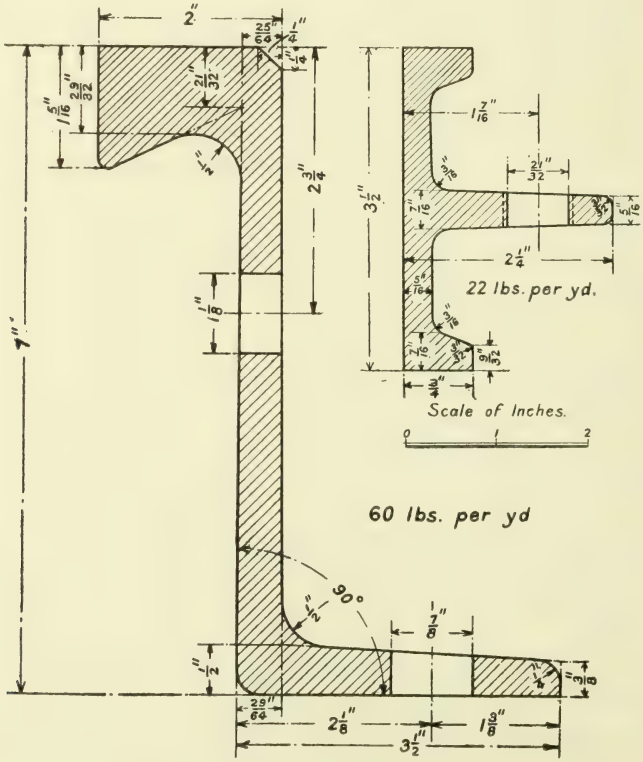


Fig. 16.

Over each insulator a hand hole is left so that the insulators can be readily replaced without damaging the road. This hand hole is covered with a flat plate, on which the ordinary street paving blocks are laid, there being nothing on the road surface to indicate that a hand hole exists. On the L.C.C. system, a cast-iron frame is used (see Fig. 13, Plate I), and the edges of this frame are seen on the road surface. The insulators require little or no attention, and it is therefore preferable to use the flat covers and pave right over them.

The conductor bars are divided into sections in accordance with the Board of Trade requirements. The section insulator consists of a gap in the conductor bars, the length of the gap being long enough to clear the length of plough contacts and prevent an arc being drawn across. The conductor bars are bent outwards at the ends, so as to readily receive the plough, leaving the last section without any further guide. At the section insulator the ends of the conductor bars are not fixed to the insulator, but the fixture is made by means of double insulators about 2 feet from the end of the bars. By this means the necessary elasticity is given to the conductor bars to prevent the shock of the plough striking the bars breaking the insulators. Fig. 15, Plate I, shows the plough or collector.

The arrangement for cleaning is shown clearly on the illustration. Cleaning pits are placed about 120 feet apart, and over these pits a cover is fixed. Sump pits are placed about 360 feet apart. A cast-iron hood is fixed over mouths of sewer pipes to form a trap to keep back sewer gas. The cleaning pits are used for cleaning the conduit of small accumulations of dirt without drawing it over to a sump.

This completes the description of the straight track work for a side slot conduit, and it only remains to refer to the design used for points and crossings.

Wherever a turnout or special work occurs it has been the practice to divert the slot from the side to the centre of the track. This has been necessary, owing to the difficulty of supporting the movable slot point in a satisfactory manner. Owing to this change, from side to centre slot, it will be seen that the plough or collector has to move automatically across the track when the car passes from side to centre slot. This is accomplished by the plough-head being mounted on girders on which it is free to slide. In the case of Bournemouth, the plough is raised from the conduit when it reaches the end of the conduit line, and is lifted by a plough raising gear and taken up under the car. The conduit is diverted from the side to centre for

this purpose, so that when the plough has to be raised, it is always in a central position between the rails. When in this position the centre cast-steel piece on the top of the plough engages with a lifting piece made to fit it.

The time taken to change over from the conduit to the trolley system on lines in actual operation is from nine to twenty seconds. Fig. 17 shows the finished track with side slot conduit at Bournemouth.

We can now take up the costs, both as to capital, operating and maintenance.

Fig. 17.

The author has given a table, showing the costs of the most important parts used in the construction of the tramway.

In order to shorten this paper as much as possible, he has collected the tables giving the cost of construction, operating and maintenance together, and given them as an appendix. It will be seen from the tables that the difference in first cost between the Lorain surface contact and the conduit system amounts to approximately £2,000 per mile of single track. It is not proposed to deal with this

difference in cost of construction in any way, beyond calling attention to the amount, because this only affects the question to the extent of a fixed annual charge against the undertaking. The features of particular interest in comparing the two systems are referred to in a report given by Mr. Shawfield, Borough Electrical Engineer, Wolverhampton, to his Committee when reporting on the system, viz.:—

(1) Safety for human beings and animals.
(2) Reliability.
(3) Consumption of electrical energy per car mile.
(4) Cost of working and maintenance.

In dealing with the first of the above points, the author thinks it will be readily admitted that in all surface contact systems, however perfect, certain dangers exist. The exact extent of the danger will depend largely upon the care with which the system is maintained. In this connection, it is worthy of note that in the Wolverhampton system the whole of the cables are laid on the solid system. This was done, the author believes, at the express command of the Wolverhampton authorities, the Lorain Company contending that the draw-in system is equally suitable. On this point the author has very strong opinions. He believes that the fact that the cables are laid on the solid system is of the utmost importance to the success of any surface contact tramway. He believes that, so soon as any surface contact system is laid with the conductors between the surface contact boxes placed in draw-in tubes, trouble is sure to result, and the system would ultimately fall into disrepute.

He has said that the danger will depend largely on the care with which it is maintained. He does not mean by this that necessarily a great many men will be employed on the maintenance, but rather that the men so employed must be conscientious in the discharge of their duty.

Regarding the safety of the conduit system there is little to be said. It is almost impossible to imagine how an accident due to electrical causes could happen. In this particular, the author believes the conduit must always be superior to any surface contact system that has been, or is yet to be, designed.

The reliability of the system depends, so far as the surface contact is concerned, on freedom from breakdown on the cable between the boxes, the satisfactory operation of the contact mechanism and the proper maintenance of the insulation. The question of the collector gear, both as regards the surface contact and conduit, can be left

out, as any troubles that might arise in this connection can be made right.

The freedom from cable breakdown is reasonably assured on the Wolverhampton system, owing to the solid system being adopted, as already referred to. The satisfactory operation of the mechanism is, the author thinks, also to be depended upon, but the question of maintaining the insulation in the contact boxes is, in his opinion, questionable, although it is only fair to state that, up to the present, the Lorain system at Wolverhampton has surpassed any surface contact line yet constructed.

At Wolverhampton most of the live studs are found at passing places, and the studs at these points are consequently more carefully looked after, and more frequently tested. The average number of studs found alive per month from July, 1902, until February, 1903, was seven at between 10 and 49 volts, and five between 50 and 500 volts. Since that time the author believes that Mr. Shawfield has introduced a maximum automatic time setting cut-out, which materially reduced this difficulty.

The trouble in this connection was chiefly caused by scrap iron on the track, causing short circuits. The question of live studs is naturally the first difficulty that appeals to any one discussing surface contact, as it is a question that affects both the reliability and safety. In connection with the reliability of the conduit system, it can be said that there is nothing except the collector to go wrong.

The conductor bars are mechanically well fixed, and the insulators are, owing to their position, free from risk of breakage, and this ensures the insulation being efficiently maintained. The risk of leakage is less than on any other known system.

Regarding the consumption of electrical energy per car mile, the surface contact system is handicapped at the outset by the current for exciting the magnets, and the consumption due to carrying the magnets and collector gear, the weight of which, as has already been stated, amounts to about one ton. Mr. Shawfield gives this as follows :—

		Units per Car Mile.
1.	Excitation of magnets	·111
2.	Extra weight of Lorain equipment	·131
3.	Leakage current...	·008
	Total	·250

The author regrets that he has not a table giving the actual current consumption per car mile for a conduit tramway in this country, but

he thinks we may safely assume that it will be the same as a trolley line or a surface contact line, except for the figures given above. This means that the extra consumption on the Lorain system amounts at present to a quarter unit per car mile, and this quite independently of the number of car miles run.

Regarding the cost of working and maintenance, you will notice that the author has given a table relating to the Metropolitan Street Railway of New York, and he thinks this may be taken as a fair basis for comparison, except as regards generating costs for electricity supply.

The Metropolitan Street Railway Company of New York supply power from their own power house, specially run for the street railway, whereas, at Wolverhampton, the Tramway Department purchases the supply from the Electric Light Supply Undertaking, owned and worked by the Corporation. The difference in operation cost per car mile is 1·16 pence, being the difference between 5·08 at Wolverhampton and 3·92 at New York, but it must be borne in mind that the car mileage in New York is very much greater than in Wolverhampton, as shown on the tables.

Regarding maintenance of permanent way, rolling stock and electrical equipment, this shows very much in favour of the conduit.

The Lorain system works out at ·96 per car mile as against conduit ·575.

It is possible that conduit lines in this country will cost at the first more to operate than the New York line, but the author feels that as the experience of the staffs increase, the figures obtained abroad will be easily realised in this country.

There is a great deal more to be said, but the author is afraid he has already engaged your attention too long. He should have liked to have dealt in detail with the life of the various parts of surface contact and conduit systems, and, from the complete criticisms, worked out a full tabulated statement, but it is impossible to bring all this within the scope of such a short paper. He must therefore regretfully conclude what he feels is but a general outline of the subject. He cannot conclude, however, without mentioning that he claims nothing in this paper as original. He must express his indebtedness to Mr. Shawfield, Mr. Wetmore, Mr. Connett and Mr. Wilcox, for the assistance they have given him.

APPENDIX I.

CAPITAL EXPENDITURE PER MILE OF SINGLE TRACK.

Lorain Surface Contact, 4 feet 8½-inch gauge.

	£	s.	d.
Permanent way only	5,500	0	0
Lorain equipment	2,500	0	0
Total per mile of single track ...	£8,000	0	0

The above includes contingencies and sub-surface obstruction to a depth of 9 inches below surface of rails.

Cost of Side Slot Conduit, 4 feet 8½-inch guage.

	£	s.	d.
Rails, wheel and slot, with joints and tie bars	2,460	0	0
Rails, conductors and bonds	350	0	0
Insulators	200	0	0
Castings, yokes, covers, &c.	1,300	0	0
Haulage	60	0	0
Excavation	470	0	0
Concrete	1,650	0	0
Drainage and Contingencies	650	0	0
	£7,140	0	0
Paving, new granite setts	2,850	0	0
Total ...	£9,990	0	0

Say £10,000 per mile of single track.

The above only include minor contingencies, but not heavy sub-surface obstructions.

APPENDIX II.

WOLVERHAMPTON CORPORATION ELECTRIC TRAMWAYS.

Operating, Maintenance and General Costs for six months ending 30th September, 1903.

Analysis of Costs.	Totals for six months. April to September. £	s.	d.		Average cost per car mile, April–Sept. Pence.	
OPERATING COSTS:						
Electricity	2,813	11	9	...	2·54	
Wages of Motormen, Conductors, Inspectors, &c.	2,080	12	7	...	1·88	
Wages of Oilers and Cleaners ...	212	17	1	...	·19	
Oil, grease and sundry stores ...	107	17	1	...	·09	
Track—watering and cleaning ...	56	6	7½	...	·05	
Sand and Salt	8	8	7	...	·007	
Tickets, Way Bills, &c.	79	14	4	...	·07	
Coal, Water and Light	163	13	6	...	·14	
Uniforms	90	0	0	...	·08	
Miscellaneous	15	4	8	...	·01	
Total Operating Costs				£5,628 6 2½		5·08
MAINTENANCE AND RENEWALS:						
Permanent Way	£272	5	9	...	·24	
Feeders and Conduits	23	2	8	...	·02	
Rolling Stock	463	8	6	...	·42	
Buildings	36	3	9	...	·03	
Tools	30	4	11	...	·02	
Total Maintenance and Renewal Costs ...				825 5 7		·74
MAINTENANCE OF LORAIN EQUIPMENT:						
Car Equipment:—						
Repairs to Magnet Systems " Switches and Batteries and charging; " and maintenance of Skates	£59	0	0	...	·05	
Inspection and adjustment of Magnets and Skates	64	5	2	...	·058	
Line Equipment:—						
Inspecting and Testing Boxes ...	47	17	9	...	·04	
Repairs and maintenance of Contact Boxes and Cables ...	72	18	6	...	·066	
Total Maintenance cost of Lorain Equipment				244 1 5		·22
GENERAL CHARGES:						
Management	£225	0	0	...	·20	
Engineering and Clerical Staff ...	220	5	4	..	·198	
Rent, Rates and Taxes	193	0	0	...	·17	
Insurance	202	0	3	...	·18	
Printing and Stationery	132	9	8	...	·12	
Miscellaneous	69	2	9	...	·06	
Cost of Management of Loans Fund	60	0	0	...	·05	
Total General Costs				1,101 18 0		·99
Total Working Costs				£7,799 11 2½		7·04

Car Mileage = 270,979.

APPENDIX III.

THE METROPOLITAN STREET RAILWAY COMPANY, OF NEW YORK.

Operating, Maintenance and General Costs for twelve months ending 30th June, 1898.

	Pence.	
MAINTENANCE OF WAY:		
Repairs roadbed—track, labour	·045	
" steel rails	·005	
" switches, castings, spikes, &c.	·02	
Repairs, underground construction	·04	
" tube cleaners	·03	
" of buildings	·005	
Removal of snow and ice, and street cleaning	·02	
Total ...		0·165
MAINTENANCE OF EQUIPMENT:		
Repairs of cars and vehicles	·20	
" electrical equipment of cars	·21	
Total ...		·41
POWER:		
Repairs of steam plant	·015	
" electrical plant	·005	
Renewals of Horses	·02	
Horse shoeing	·015	
Cost of provender	·10	
" feedmen—wages	·01	
Hostlers, Hitchers and stable help	·09	
Engineers, Firemen and power service	·145	
Fuel, power houses	·36	
Light and other supplies at power house	·04	
Water Tax	·04	
Total ...		·84
TRANSPORTATION:		
Conductors, Drivers and Motormen	2·485	
Inspectors, Starters, Switchmen, &c.	·355	
Car house expenses—Watchmen, Car Cleaners, Oilers, &c.	·195	
Car service—car lighting	·01	
" oil, waste, &c.	·035	
Total ...		3·08
GENERAL EXPENSES:		
Salaries of Officers and Clerks...	·08	
Injuries and damages	·305	
Other general expenses	·225	
Total ...		·61
Total Operating Expenses...		5·105

Car Mileage = 7,110,090.

BRIEF NOTE REGARDING CLARET SYSTEM.

See Figs. 1 *and* 2.

The current from the Central Station Dynamo *G* is sent by an underground feeder *X* to a series of distributors or automatic relays, which are placed along the track every 100 metres. From the distributors start a series of small wires, which supply current to each of the contact blocks placed between the rails. These contacts are formed of a simple metallic block embedded in the pavement, and are slightly raised above the surface, so that the contact rail which the car carries underneath it can rub over the upper surface. This succession of blocks which receive the currents only at the instant when the car passes serve to distribute the current for the motors. As the car continues on its course its contact rail touches the block which is immediately in front without having left the preceding one. As the forward contact is connected to the distributor by one of the wires a small portion of current is shunted into the distributor and serves to operate a fine wire electromagnet of high resistance which forms part of the distributor. The latter acts as a relay, and sends the main current into the new block, cutting it off from the preceding one, from this time on the current for the motor is furnished entirely by the new block, until it is in turn replaced by the succeeding one, and so on.

DISCUSSION.

Mr. Miller

The President, Mr. THOMAS L. MILLER, said—Before asking you to join in the discussion on the paper to-night, I would like to make one or two remarks with regard to it.

The author has referred to the Blackpool conduit, as being the first attempt to establish the conduit tramway system in this country, and it will be interesting to the members of the Society to know that one of the first descriptions of the system adopted by Mr. Holroyd Smith, at Blackpool, was given in a paper read by that gentleman, before this Society, some 20 years ago.

At that time Blackpool had not taken up the system, and Mr. Holroyd Smith was experimenting with a short line laid down in some works at Cornbrook, Manchester, and an excursion was made by the members of the Society to Manchester, to inspect the operation of this experimental line.

Dealing with the conduit system generally, the author made reference to certain drawbacks in its operation, but has not mentioned one matter that has been brought forcibly before us during the late wet season, namely, the difficulty experienced in working it in certain low-lying districts, owing to the flooding of the line.

I notice, again, that the author has referred to the question of car mile consumption. This is a matter which has been lately taken up by Mr. Ryder, in his book on "Electric Traction," where he points out that, owing to the great difference in the size and carrying capacity of cars, the "car mile," as a method of comparison, is somewhat unreliable, and he suggests, as an alternative, that the "ton mile" should be substituted for it. Of course, neither method is absolutely correct, but the variation in weight, due to a greater or less number of passengers being carried, would, it is thought, be likely to give more uniform results if the "ton mile" were adopted as a basis of comparison.

In dealing with the cost of the respective systems, the author has given us certain figures, and these I would like to supplement by one or two notes which I jotted down before coming to the Meeting this evening.

In Chicago, in the city or central districts, the cost of the conduit

system worked out at £21,200 per mile of single track, while in the out-districts the cost amounted to £15,200 per mile of single track, while the average cost throughout the whole district amounted to £16,055, and the average cost of alterations and deviations to £1,400 per mile of single track, making a total of £17,455 per mile of single track. Mr. Miller

In the case of the London County Council, according to the figures given by Mr. Ryder, the cost was £13,660 per mile of single track, the additional cost of the alteration of pipes and other underground obstructions being taken at about £800 per mile of single track. This is the figure given for the Tooting lines, but the latter figure in the City districts of London would, I anticipate, be very largely increased.

One of the difficulties to be contended with in the conduit system is the cleaning of the conduit, and it is interesting to note that at Paris the cost of cleaning the conduit amounts to £118 per mile of single track per annum, while in London, Mr. Ryder estimates, the cost would be about £100 per mile of single track.

In dealing with the question of working costs the author states that he regrets he has not a table giving the actual current consumption per car mile for the conduit tramway in this country. In this connection it is interesting to note that the cost of working the conduit system at Brussels is found to be ·3125d. more per car mile than with the overhead system, and that in Paris the costs per car mile were ·0495d. in favour of the overhead system.

Comparing the costs of conduit and overhead trolley, I would point out that the Greenwich lines of the London County Council on the conduit system were estimated to cost £14,041 per mile of single track, including rails, road-work and platelaying, &c., whereas the costs for the overhead system, including rails, road-work, platelaying and overhead line-work, amount to £7,496.

I mention these figures because I think it well, although the author has studiously avoided it in his paper, that a comparison should be made between the conduit system and the present overhead trolley system, as it is only by making such comparison that it is possible to appreciate how very heavily the cost of the conduit system must handicap an electrical undertaking, and that however much one may wish to do away with the unsightly trolley lines, one has, after all, to judge the matter on strictly commercial lines.

Judged in this manner, it will be seen that the charges for interest and sinking fund would prove so heavy a burden to the undertaking,

Mr. Miller that as at present constructed and at present prices, it would appear that the use of the conduit system is only possible in densely populated districts, where a quick service of cars is established, and where the interest and sinking fund charges would form a comparatively small proportion of the total costs.

I cordially agree with the author's remarks with regard to the laying of the cables at Wolverhampton on the solid system, as I believe it is the most reliable system on which to lay cables.

Mr. Pain Mr. Coard S. Pain said—I understand that there is some new system of tramway being introduced in Dublin at the present time, and I should feel obliged if the author would tell us if it is either of these systems, and if so, which?

When I was interested in tramways, and some years ago, when rope traction was introduced, it was considered that a great deal of trouble would arise from the amount of water and dirt that would get through the slot into the rope conduit, and so far as I can judge from the paper, the same thing might apply to some of the systems that have been described.

Mr. McHaffie Mr. H. G. McHaffie said—On page 295, the author says, "Over "each insulator a hand hole is left, so that the insulator can be readily "replaced without damaging the road. This hand hole is covered with "a flat plate, on which the ordinary street paving blocks are laid, there "being nothing on the road surface to indicate that a hand hole "exists."

I should like to know, in the event of a breakdown, how one is to find the insulator?

Then on page 298, the author mentions trouble caused by the studs being left alive. Is that not easily got over by some method of short circuiting the studs? It seems to me that it ought to be possible to overcome this difficulty.

The President mentioned the difficulty of "flooding." Well, I think, that must be a very serious difficulty in many towns, and I think, from that point of view, that perhaps the surface contact system would be safer.

I should just like to know, however, how the insulation of the contact box is ensured—if it is thoroughly watertight?

Mr. Wilson Mr. H. W. Wilson said—I was very much interested in the paper, but there are one or two matters which struck me as omissions. First of all, the author has not mentioned the Kingsland surface contact system, which has not been practically tried in this country, but in experimental lengths has done very well. I believe that this

system is being tried in Dresden on a large scale, and I should like to know what the author thinks about it. Mr. Wilson

I do not think that the author has pointed out with sufficient clearness the limitations of these surface contact and conduit systems, and by limitations, I mean financial limitations. The author has stated the figures of cost per mile of track for both conduit and surface contact lines, and I think we may take it that his figures are not too unfavourable to such systems. If you compare these costs with the cost per mile of a trolley system, it is evident that, except for districts with a very high traffic density, anything except an overhead trolley equipment would be altogether crushed by the interest and capital repayment charges.

There is, also, a point in connection with the operating costs upon which I should be glad of further information. The author says that in Wolverhampton the cost per car mile for energy is 2·54d. He also points out that it takes about ·25 of a unit per car mile to move the extra weight of the Lorain equipment, and to excite the lifting magnets, so that approximately you use 25 per cent. more current with the Lorain surface contact system than you do with an overhead system. It would appear also that the cost of energy per unit in Wolverhampton must be very high to account for the cost of 2·54d. per car mile.

Again, the cost of upkeep per car mile on the Wolverhampton system appears to be very heavy indeed. I should like to know if the author thinks that this system will ever do more than cover working expenses and interest and repayment charges.

As regards the London County Council conduit system, we have there to take into account the fact that the traffic density is very great, and the receipts per car mile correspondingly high. I am not certain of the exact figures, but I believe the London County Council are getting very good receipts per car mile; at the commencement it was something like 2s., and if that continues, of course, their tramway system ought to pay very well, but otherwise, even in London, a conduit system such as that described may in the end prove too expensive, because, personally, I may say, I think that any conduit system must in the long run cost more to keep up than a well constructed overhead system.

The President gave some figures concerning Brussels and Paris, as regards the extra cost of running a conduit system over a trolley system, but he did not say whether the figures he mentioned were for the extra cost of current only or for the total extra cost.

Mr. Miller The PRESIDENT—No, total *increase* of cost.

Mr. Wilson Mr. WILSON—With respect to the Wolverhampton system again, the author on page 289 says :—

"In the car sheds, to excite the magnets to start the car a small "accumulator battery of eight cells is used, and this battery is also "used in cases of emergency."

I assume that in starting the cars they only send the current round the series magnet, as the voltage is not sufficient to properly excite the shunt magnets, and I should like to know whether one magnet is sufficiently powerful to raise the armature of the contact maker.

Mr. Collins Mr. BRIERLEY H. COLLINS said—I should like to ask the author whether it is possible to reduce the height of the contact studs above the paving. He mentions that the centre of the cover is $\frac{3}{4}$-inch above the surrounding paving. I should have thought this would be detrimental to the traffic using the roads, and that to reduce it to an infinitesimal amount would be a great convenience to the traffic generally.

I noticed from the papers recently, that one of these studs had been left alive and an animal had been electrocuted in Wolverhampton, and that other trouble had happened to passers by, but it appears that these accidents cannot be absolutely avoided, and are not unknown in other systems.

With reference to the London County Council Tramways, I happened to be travelling in one of the South London trams a few months ago, which was delayed on the way, and am glad to have the author's assurance as to the only trouble being due to a batch of defective collectors and ploughs, because I waited a quarter of an hour for the car to proceed. On enquiry, I was informed that the current was cut off, but could not obtain a satisfactory explanation. I asked if that was a usual occurrence on the south side of the river, and the reply was "yes." From an æsthetic point of view the conduit system is the best, but under British climatic conditions and with regard to first cost and up-keep, experience leads us in the direction of the overhead system.

Mr. Priest Mr. FRANK E. PRIEST said—I do not understand how it is better to use the ton mile measurement in lieu of the car mile measurement referred to by the President, inasmuch as the weight of the passengers could not be known, and therefore, might be taken on a wrong assumption.

Referring to the words of the author on page 295 :—

"The insulators require little or no attention, and it is therefore "preferable to use flat covers and pave right over them." I should expect that the views of the department in charge of the streets would differ materially from those of the author. Mr. Priest

I would like to know what led to the studs in the Lorain system being left alive: was it that the parts ceased to operate in the manner described by the author, or was it due to water entering among them?

Regarding conduit systems, whether for electric or cable traction, it seems that while in many places serious difficulty was experienced in consequence of dirt entering the conduit, there were some exceptions, such as Edinburgh, where this difficulty did not seem to be troublesome, and I attribute this fact to the steep gradients which caused the conduits to be kept clean by the surface water which entered them.

Mr. Henry H. West said—I approach this question from the æsthetic point of view. When we began with the multitude of telegraph and telephone wires over our heads, and then had the trolley wires added, we thought the arrangement was an eyesore. Now we have got so used to them at home that we do not see them; but I put it to you, if any of you go into a strange town, whether you do not at once see all the extra wires, and think what a disfigurement they are? I know that in the beautiful City of Brussels, of which our President has spoken, the first time I was there after the overhead trolley system was introduced, I thought they had ruined the place. I think it is worth while paying, and paying handsomely, for the æsthetic in our streets. I think it would be an interesting addition to this paper if the author would give us a comparison, not only between the surface contact system and the conduit system, but also between them and the trolley, or overhead system, both in cost of construction, and in the cost of maintenance and operating. Look at the picture of the Bournemouth street given in the paper, and see what a beautiful architectural and pictorial effect you get by the entire absence of that network of wires overhead. If the cost is not too great, and if the working is equally efficient and safe, I would, myself, like to see the profits of the Liverpool Corporation on their tramway system so great that they could afford to drop the overhead system, and adopt the conduit system. Mr. West

Mr. William Brodie made a few remarks as to comparison of the trolley system with the two systems dealt with by the author under various conditions. Mr. Brodie

Mr. Pain

Mr. Coard S. Pain said—I am under the impression that when the Liverpool Corporation were considering the question of electric tramways, they had various systems before them, but at that time the success of electrification was not assured, and they felt that they were not justified in going to an expense such as would have been involved in adopting either of these systems.

Mr Balfour

Mr. George Balfour, in reply, said—With reference to the first remark that was made by the President, I was pleased to note that the Society has been associated with the Blackpool line.

I immediately get on to contentious ground. The President raises the question of the London County Council Tramways and flooding. Flooding has occurred on the London County Council system, and will occur so long as we get weather such as we have had recently. It was never anticipated that we should have such downfalls. In any system of tramways, at all, even horse tramways, when a certain set of circumstances arise, you have to shut your system down.

I may make my position perfectly clear in this matter. I am interested in conduit systems, I am not interested in surface contact systems. I am putting before you the two systems, and you must come to your own conclusions.

Now, with regard to the London County Council system, flooding has only caused stoppage once. The stoppages have been due to one or two causes, defective ploughs, not having men trained to their work, &c. Leaving out the first week or two, they have had no trouble at all, except in regard to the collectors. The first collectors supplied are working very satisfactorily. There were a large number of collectors delivered, made of bay mahogany in place of maple wood, coated with pitch instead of a special compound. These ploughs broke down one after the other. That is no defect in the conduit system. You might have the same difficulty in connection with trolley plants. But I want to make it clear, that so far as the conduit system is concerned, that is, the construction of the road and the insulation—nothing has gone wrong.

With regard to the point which the President raises—the question of cleaning—I think the London County Council costs will come out at nearly £100 per mile, but this will be reduced as they gain experience in the way of cleaning the conduit. Further, you must not take the cost for London as the cost for a provincial town. What will cost £100 in London, you can put at £60 in Liverpool. £40 to £50 per mile of track is an ample estimate in a provincial town.

It has been proved that the method of fixing the conductor bars in the conduit is as near perfect as anything can be. Mr. Balfour

Mr. Pain asked about the Dublin surface contact system. I have never heard of one being adopted there.

Mr. McHaffie referred to the question of the hand-holes of the insulators, and was anxious to know how you find them. It is very simple. At certain points along the slot rail there are inlet pieces which you are able to move out by two iron claws. They are all arranged for a certain length, so that you can withdraw a conductor bar without having to alter your position. It is only a matter of a man measuring from the nearest opening which is used for repairing the conductor rail, and so arriving at the exact position. The construction of the insulator and the almost impossibility of a breakdown is such that it would be absurd to leave the cast-iron showing on the street, when you probably would not require to touch it once in a few years. The insulators can be exactly located without measuring by feeling with a feeler through the slot in the conduit. There is no difficulty in finding the insulators.

Mr. Priest asked how the stud comes to be left alive. It is usually caused in this way. In carrying the scrap iron it hangs on to the magnet, striking the collector bar and touches the road box, and in special work it crosses another rail, and you get a short circuit, carrying a deposit of carbon on the inside of the cup. This deposit of carbon forms a conducting surface in the box and carries the current from the cable to the stud, and so makes it alive.

Mr. Wilson enquired about the Kingsland system. One point in favour of it is that it is a mechanical system, but I dislike it because it compels you to have an opening in the surface, and in addition you have all the road studs. This is the great objection, and even allowing it to work well, it seems a pity to have a slot in the roadway and studs at the same time.

I am aware that a line has been running in Dresden, and it is supposed to operate very well.

Then Mr. Wilson also wanted me to make some remark as to the limitations of the two systems. I am not quite sure what Mr. Wilson meant, but both have limitations. In my opinion, the greatest fault of the surface contact system is that you must have thousands of points along your roads, any portion of which may become electrically alive.

Then, with regard to the limitations of the conduit system, I think we know the worst of this system. The experience is by no means

Mr. Balfour new. I mentioned in my paper the conduit system in Paris; if you make careful enquiry you will find it is the case, that the only successful tramway in Paris is the conduit tramway, and the Municipality is waiting to take control of the whole of the tramways—about 40 miles—and convert them to this system.

Mr. Wilson further raises the question of receipts per car mile in London. These are, according to the last report, 12¾d. per car mile.

The price of electricity at Wolverhampton, as delivered to the Tramway Company, is 1¾d., which, of course, is high.

With regard to the battery, it is used on the series turn of the magnets, and is ample for the purpose.

Mr. Wilson also asks why double conductor bars were used. It was because you had an opportunity of arriving at a set of conditions which Electrical Engineers have attempted to arrive at for many years. In the conduit system, the conduit is specially suited for it. It enables you to get double insulation. The conditions are in every way suitable, and it is not a question of cost at all. You get away entirely from questions of electrolysis.

Mr. Collins enquired if it was possible to reduce the height of the stud. I think it is quite impossible to reduce that. If you had less than ¾-inch, the very slightest accumulations of mud on the surface would prevent the hard copper collector strip making any contact at all.

Mr. West invited me to compare the overhead system with the conduit system. I was particularly careful not to refer to the overhead system. I may state frankly, that for most provincial towns in England, there is no hope for anything but the overhead system. I would not put forward a conduit system for a small provincial system, but wherever there is a possibility of an earning capacity sufficient to pay standing charges on a conduit line, then I would recommend the conduit system. I may say that the capital cost of the conduit system comes out at about £10,000 per mile, and that of overhead equipment at about £6,700 per mile, so that you have a saving of £3,300 per mile in round figures.

The President referred to the capital cost of the London County Council Tramways as £13,000 per mile. There were several specialities introduced in the construction of these lines, but I may state that the cost given above is absolutely the cost of the Bournemouth construction.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

TENTH MEETING—9TH MARCH, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Mr. EUSTACE THOMAS, as a *Member;* and Mr. JAMES H. MEIKLEJOHN, as an *Associate Member.*

MODERN MARINE BOILER FAILURES.

BY J. RENEY SMITH, M.I. Mech. E., M.I.N.A.

IT would appear upon first consideration that modern boiler design has reached a state of perfection, but the many recent failures, more or less costly, has led the author to bring the question before this Society, in the hope that a discussion upon the points raised will prove of benefit to all.

It is not necessary to enlarge upon the failures due to neglect, as these, though of course serious, involve a question of "personel," and with which each superintendent is best able to deal. It will be more profitable to confine consideration to those cases which have occurred in boilers worked by capable and skilled engineers, and also kept perfectly clean, using feed water from which oil and air have been removed and general care taken in their working.

The failure of furnaces so frequently met with in boilers worked under these conditions, brings the question of design into consideration as a possible reason for their occurrence.

It has been found by experience that the old fashioned plain furnace was much less liable to distortion than the modern ones of the various sections generally met with in high pressure boilers, and the collapse of which is probably due to their design. It is found that these corrugated furnaces, as a rule, distort, as shown on diagram "A," the distortion gradually increasing in amount until it is necessary to effect a permanent cure by the renewal of the furnaces, "jacking back," to a true form, seldom being more than a temporary measure, and always looked upon with more or less suspicion by those responsible for their safe working.

A theory the author advances is, that with the modern sections of corrugated furnaces of all types, this distortion is due entirely to the unequal rates of expansion longitudinally and circumferentially, which is taking place constantly under the ordinary working conditions, such expansion distorting the furnace from true form, and finally becoming permanent, reducing the efficiency of the tube or even condemning it.

Referring to diagram "A," it is seen that as the flame passes from the front of the furnace to the combustion chamber, the greatest heat will be at the lower part of the corrugation facing the direction of the flame, the upper part of the furnace expanding considerably more than the lower. The result of this expansion longitudinally is, that as the front and back plates prevent an increase in the length, the furnace is compressed and the corrugations are closed, the effect being greater on the upper than on the lower part of the tube. There is also an increase in a vertical direction with a combined result that the furnace is flattened in the manner shown in diagram "B," this flattening being greatest at the combustion chamber end where the corrugations are exposed to the greatest heat, and where, in fact, the furnace usually fails. The result is, of course, accentuated in boilers using forced draught, and is also more marked in a furnace of large diameter or deep corrugations. The effect is most marked in a double ended boiler with a combustion chamber common to two furnaces as shown in the drawing "C." In this arrangement the furnaces and chamber may be taken as a beam equally pressed all round and securely held at each furnace mouth. The effect of expansion in this case is distortion of the furnaces as described, together with a sagging effect and consequent failure of the back tube plates and saddle corners, due to the comparatively weak form of these plates below the lower stay tubes. The weight of the combustion chamber acting at the centre between the furnaces increases the trouble. This distortion is probably constantly occurring during

the working of the boiler, but disappears when the cause is removed; continued long enough, the material loses its elasticity and is less able to return to its original form, and permanent distortion commences. In other words, the continual change from tension to compression on the inner and outer surface of the corrugation must in time inevitably lead to failure. In order to mitigate this evil the author would suggest, as the original design for all high pressure boilers using this type of furnace, a form of attachment for the furnace backs now so commonly adopted as a method of repairs. This arrangement is shown on drawing "D," where it will be seen that the back of the furnace is contracted in area, the corrugation tapering off in a bottle neck shape, flanged outwards to join the saddle piece, which is secured to the tube plate and combustion chamber in the manner shown.

This method allows very largely for the working of the furnace by taking up the movement in an easy manner, and reduces the risk of collapse to a minimum. It has also the great advantage of keeping the back rivetting away from the direct action of the fire, thus preventing the annoying experience of cracked and leaky landings, and also ensures better workmanship, the rivets being more accessible than in the ordinary attachment.

It is the experience that in boilers fitted with this bottle neck type of furnace and separate saddle plate, the horizontal landings in the combustion chamber sides, which had previously given great trouble through leakage, have since remained perfectly tight, proving that the end pressure on the plates due to the working of the original furnaces has been practically removed.

With regard to the failure of combustion chambers due to causes other than deposit, it will be seen from the drawing that these are largely owing to defects in the original design, a double ended boiler with a common combustion chamber to both furnaces being much more affected by fluctuations of temperature than the more modern single ended type.

The drawing marked "C" shows the usual arrangement, with no provision for effectively taking the weight of chambers, &c., consequently leakage is practically inevitable. In the single ended type it will be seen that this weight is carried by the back stays to a certain extent, but the author would suggest that vertical stays, as shown, should be fitted, to relieve the back stays from a cross breaking strain.

It may be advantageous to draw attention to the usual method of testing boilers after repairs, the practice being to impose a load of double the working pressure, which probably does the structure more

harm for future working than is compensated for by its supposed test for strength. It is quite possible to carefully examine the section of material without unnecessarily straining the boiler, and this is all that is required to ensure the original strength of structure, and the author contends that the test pressure after repairs should only be imposed for workmanship, and that one and a half times the working pressure should be ample for this purpose. The reply usually given to this contention is that it is only possible to discover corroded stay ends in accessible places by subjecting them to a severe test, but it is only reasonable to suggest the possibility of straining them beyond their limit of elasticity only short of rupture, and so rendering the stays less able to sufficiently withstand the loads placed upon them.

The frequent failure of smoke-boxes, uptakes and funnels, is one largely due to a careless consideration of the requirements of such fittings, no provision being made for properly supporting the weight or allowing for any strains due to expansion, and the only remedy for this is that means should be devised to carry the funnels and attachments to a structure external to the boilers themselves. The drawing "E" shows the arrangement usually adopted to overcome original defects, and which has been found quite efficient.

The author trusts that this short paper may raise some interesting points for discussion, and relies upon the large practical experience of many present to render the consideration of the difficulties mentioned a profitable one, and if this object is attained he will be fully recompensed for the slight trouble he has taken in bringing the matter to your notice.

The Paper was Illustrated by Plans, Diagrams and Models.

DISCUSSION.

Mr. W. J. Willett Bruce said—I am sure the author has given us a very interesting paper on failures which have come under his notice, and I feel we are indebted to him for the fine set of drawings placed at our disposal. Mr. Bruce

He alludes to the keeping of the boilers perfectly clean, and feed water free from air and greasy matter, and, I consider, disposes of it as an established fact that it is practically done; but I desire to point out that while it is a simple matter to prevent the presence of the first two of these, by having the opportunity at your disposal and a satisfactory arrangement of feeding, as regards the latter, that though in reduced quantities, it does get into the boilers somehow or other, in spite of, in many instances, careful use and disposition of internal lubrication and efficient filters; and I may, I think, safely say that though there are many good filters on the market, there is not one, even the best of them, up to the present time, which will totally eliminate and extract the whole of the oil, and some portion is bound to be carried over, and that portion unfortunately does the mischief.

As regards the collapsing of furnaces, I am pleased to say that the majority of cases that have come under my notice have not been due to any bad error in design, but through grease, and in one instance through a most unfortunate accident caused by the presence of a large amount of solid deposit which was brought in with the feed at a time when the boilers were almost laying under banked fires and at rest, and during this state of inactivity accumulated on the furnace crowns, and upon the fires being put in order and the pressure raised ready to supply the coming and known requirements for cargo purposes, it was discovered that several of the furnaces had collapsed so badly as to almost prevent the fireman getting his rake through the fires, and I assure you that it was a long time before the proper explanation of how this happened could be arrived at, as the whole thing was wrapt up in mystery.

Referring to the author's suggestions about staying up the combustion chambers, I think I understood him to say that it was a fixed stay. If that is so, I cannot see its purpose or utility, and how it can be effectual, as it is impossible for it to accommodate itself to the existing condition of temperature.

Mr. Bruce The author referred to smoke box casings dropping and the cause, and I was rather surprised and sorry to hear that such an important matter of design was always relegated to a junior draughtsman. While I quite agree with his remarks as to the lack of proper support to effectually carry the whole weight, and also the remedy as shown by drawing "E," I strongly consider that the carrying up of the weight of the casings and funnel proper should be separately arranged for, especially in the case of large funnels, which should be supported and absolutely carried by having suitable gusset brackets secured to the sides of the deck house, while the upper portion of the casing should be so arranged as to telescope up into the funnel proper, but in no way attached to it, and thus free to accommodate itself to existing conditions of change of temperatures, and again, by this method the casing is entirely freed from the excessive and unnecessary weight of the funnel, which is in most cases accountable for the dropping down and shearing of smoke-box studs. In my opinion this is the most effectual way of overcoming this difficulty, and should in the original design be arranged for.

Mr. Geddes Mr. Chris. Geddes said—With most of what the author has said in the paper we have just had the pleasure of listening to, I am quite in accord, but there are one or two points that I confess I am not quite so clear about.

For instance, he draws attention to, and does not approve the method in vogue of proving old boilers by testing them to double their working pressure, but I am not sure that this is altogether an unmixed evil, because, after all, the powers that be who impose such severe tests, have only for their object the safety of the public, especially that section of them who have the daily care and management of these boilers, and whose risk is so great in the event of a mishap occurring.

If it is considered necessary to test a new boiler by pressing it to double its working pressure, why not at the end of eight or ten years? You have still the same object in view and should have the same factor of safety.

I agree that design enters largely into the question of the frequent failures in modern high-pressure marine boilers, and the practice of leaving the combustion chambers in double ended boilers without other support than is afforded by the rigidity of the furnaces, cannot be too strongly condemned, for to this, and the even more frequent practice of turning the flange of the furnace round into the reverse flange, by an almost right angle corner instead of an easy radius, is

due in most instances the trouble of cracked saddle corners and leaky streams at the back ends. Mr. Geddes

With regard to the question of collapse and distortion of furnaces, I have no hesitation in saying that the most fruitful source of trouble in this respect is oily deposit.

Most steamships nowadays are fitted with one or other of the many excellent feed water filters on the market, but if too liberal a supply of oil is used,—or it is of a quality whose vapourising point is lower than the temperature due to the pressure of steam carried,—then it must of necessity be volatilised, and a portion of it will be carried over into the boilers, probably in a state of emulsion, though the bulk of it would, of course, be arrested by an efficient filter.

As an illustration of how thin a film of oil is required to produce a mishap in high-pressure boiler furnaces, I may instance a case which I had to investigate in company with a prominent Liverpool engineer. A vessel put into Falmouth with a local collapse in one of her furnaces, which on examination by my friend and myself proved to be a depression on the plain part of the furnace (between the last corrugation and the flange), in the form of an inverted cone $2\frac{1}{2}$-inches deep, and was thinned by stretching at its apex from $\frac{1}{2}$-inch to $\frac{1}{8}$-inch thick. The cause of this was afterwards discovered in the bottom of the boiler—a dab of putty, used no doubt by the boiler scalers to hold a candle or a lamp on.

I may say that neither in this nor any other of the furnace failures I have had to investigate have I found direct evidence of the real cause of the mishap at the injured part, and the reason is obvious. If oil is the cause of a plate becoming so overheated as to destroy its factor of safety, then it is hot enough to distil and destroy all trace of the presence of that oil, and evidence must be looked for not on the upper part of the heating surface, but on the under side of the tubes and furnaces, the lower parts of the combustion chambers, and the stays and shell plates at the water level where it invariably manifests itself.

Mr. J. P. Kemp said—Having dealt with some of the weaknesses of marine boilers so well, I think it is a pity the author has not included in his paper some remarks relating to water-tube boilers. Mr. Kemp

The resistance of oil to the transmission of heat is a matter which was dealt with in a paper by Mr. Stromeyer before the Institution of Naval Architects in 1902, wherein he stated that "grease is ten times "more effective non-conductor than scale, and all estimates of scale

Mr. Kemp "$\frac{1}{10}$-inch thick would be equally true of a film of grease $\frac{1}{100}$-inch "thick."

So far as I am aware the filters on board ship are mainly of the mechanical type, and we all know what poor results are obtained from mechanical filters. Systems whereby the oil in feed-water is chemically precipitated and then filtered mechanically, give greater satisfaction.

I should be glad if the author could give us some idea as to the bulging at the bends of tubes in water-tube boilers, where the scale is not very considerable, and where there is no evidence of oil.

Mr. Collard Mr. J. A. Collard said—The paper which the author has read is very interesting indeed, and although he has pointed out many defects in the modern boilers, I consider they are not to be compared with the defects with the old boilers which were fitted in vessels over 20 years ago, as it was a common thing to stop up six tubes a day.

As to the trouble with oil getting into the boilers, I do not think the filter is yet made to obviate this difficulty.

I had to do with an installation of Babcock and Wilcox boilers. All the condensed water was running to waste, and we wrote Messrs. Babcock asking if they could suggest some arrangement so that the water could be used as feed, so they agreed to put in two filters, and after they had been working about a fortnight the tubes commenced to blister and burst, and when their expert came down he found they had to give up the idea of using condensed water, as the oil was the cause of the trouble.

With regard to trouble with the up-take, I had an experience some time ago, where the vessel commenced to roll, and the stays angles gave way, and the tube doors and casing dropped, but they managed to get into Milford Haven, and had them stowed up to enable the vessel to come here to repair.

With reference to deposit on furnaces, a short time ago I was called in to examine a boiler which had only been working for three months. The furnace had come down, and the Insurance Inspector came to survey the boiler. We examined it and found it perfectly clean. We got the furnace "jacked up," and the firm who supplied the boiler said: "All we can do is to put in a new furnace," as from their experience they found that when a furnace once came down and was jacked back it was only a temporary repair and very often came down again in the same place.

Mr. Nickels Mr. Nickels (a visitor) said—As to the cause of furnaces coming down, I do not think it is altogether on account of deposit. I think

in nine cases out of ten it is due to the excessive forced draught, and I think that is caused by scale forming on the bars of the furnaces and the air finding its way through the clinker and unduly heating the particular part of the furnace; and that is the cause of many furnaces collapsing. Mr. Nickels

On the question of fitting additional supports, I quite agree with the author that it is absolutely necessary, and it is most unwise to trust simply to the bolts and studs.

Mr. Blackburn (a visitor) said—With regard to the failures of furnaces, it seems to me that the principal cause, as was mentioned by a previous speaker, is the excessive use of forced draught. You put into the hands of an engineer an apparatus which it is in his power to work to such an extent that he can in time produce the complete failure of the furnace. You have to trust entirely to his judicious management of it. Mr. Blackburn

The author has dwelt upon the double ended boiler with common combustion chamber, and the single ended combustion chamber, and I think it would have been of still more interest if he had dwelt upon the relative value of the four-furnace and three-furnace boiler in regard to their life.

Altogether, the paper has given a good deal of useful information.

Mr. Coard S. Pain said—As a point of interest, I should like to ask the author:—Why does oil, which in cold water usually floats, stick to the boiler under heat? Mr. Pain

Mr. H. B. Wilson said—I should like to ask the author, with regard to the construction shown in sheet D, as to what length of time this may have been in use? Mr. Wilson

In furnaces of the corrugated type, cracks sometimes form on the top of the corrugation, also on the bottom. These to a large extent are due to the expansion and contraction in that furnace; and it seems to me that their being concentrated in the contracted area, it is possible for the fractures to commence there.

I quite agree with the author that in all types expansion and contraction are large factors in causing fracture.

There is another point—Whether some of these failures are not, at times, due to faulty construction in other ways? Furnaces can be made too long, and be hammered up in such a way that the plate has been badly used to start with, and so commences to work, this going on until we get the fractures formed, and often owing to the manner in which the furnaces have been set in, when new.

Mr. Kershaw

Mr. J. B. C. KERSHAW said—I gather from the remarks which have been made by some of the speakers that they consider oil is the cause of many of these failures. I should like to ask whether marine engineers ever make a test to see if that is really so? I think this is a very important point, for if no tests of the feed-water for oil are ever made, marine engineers are neglecting to use a very obvious and easy method of checking these failures at their source.

Mt. Armistead

Mr. REGINALD ARMISTEAD said—With reference to our friend's remarks questioning the presence of oil in *filtered* feed-water, I may say that some friends of mine on the North-east Coast experimented, a few years ago, with a view of endeavouring to absolutely free the feed-water of any trace of oil, and by a very ingenious apparatus which they have recently brought out, which acts as a feed heater and oil extractor combined, it was found that although the feed-water had passed through a multiple filter of well known type previous to its entering this oil extractor, on the chief engineer of the vessel periodically blowing out the contents thereof into a bucket, a film of oil was found on the surface of the water, which proves, I think, that it is impossible to eliminate the presence of oil in feed-water by mechanical filtration alone.

I can vouch for the above results, as I happen to have two of such extractors fitted to vessels under my own care, and I possess samples of the feed-water drawn off from them in which oil is decidedly in evidence, although filters are used in each ship.

Mr. Miller

The President, Mr. T. L. MILLER, said—I think the principal point to be learned from the author's interesting paper is the necessity in designing boilers of carefully considering the effect of the variation of temperature on the material of the boiler, and of making ample provision for the expansion and contraction due to such variation in temperature.

Referring to the question of oil on the heating surface, I would point out that it is not so much a question of the thickness of the oil as the fact that another media is introduced between the furnace producing the heat and the water taking it up. If heat is being transmitted through the plate to some media at the other side, three resistances have to be overcome, viz. :—

(1) The resistance to the absorption of heat of the surface next the source of heat.

(2) The resistance of the metal to the transmission of the heat, or, in other words, the resistance due to the internal conduction from one surface to the other.

(3) The resistance of the metal surface to the emission of heat. Mr. Miller

Of these resistances, the resistances of absorption and emission form by far the greater portion of the temperature difference, as there is always a much greater difference of temperature required to overcome the resistances of absorption and emission, than is required for overcoming the internal resistance of the media.

It will thus be seen that the presence of another foreign substance, no matter how thin, between the heating surface and the heat absorbing media will absorb a considerable amount of the available temperature difference and will tend to greatly increase the temperature of the plates.

As an illustration, I would take the simple case of a boiler with clean surfaces and would assume a temperature of 2,500 degrees in the furnace, a steam pressure of 180 pounds per square inch, an evaporation of (say) 30 pounds of water per square foot of surface per hour and a thickness of metal of (say) $\frac{1}{2}$-inch. In such a case the following would possibly be about the temperatures one would expect.

Temperature of gases 2,500 degrees Fahr.

Temperature of surface next gases 420 degrees = difference of 2,080 degrees for absorption of heat.

Temperature of surface next water 388 degrees = difference of 32 degrees for internal conduction.

Temperature of water 370 degrees = difference of 18 degrees for emission.

That the temperature of the plate next to the gases much more nearly approximates the temperature of the water than of the gases is proved by the fact, that so long as the plate is covered by water the fusible plugs used in certain classes of boilers remain intact although subjected to the action of the heated gases. It will thus be seen that the resistance of absorption constitutes by far the greater portion of the temperature difference available for transmitting the heat to the water, and that it is quite possible for the interposition of a film of any foreign substance, however thin, by adding to the resistance, to so increase the temperature difference as to cause the plate to become seriously overheated.

Referring again to the repeated stresses brought about by contraction and expansion, the author says: "the continual change "from tension to compression on the inner and outer surface of the "corrugation must in time lead to failure." In this connection a very considerable amount of information may be gleaned from the results

Mr. Miller of the investigations of Wohler and Bauschinger with reference to the effect of repeated stresses on iron and steel.

Some of Bauschinger's tests showed that if a piece of steel is taken and tested and its elastic limit determined, it is found that owing to the treatment to which the material has been subjected during the process of manufacture, a fairly high figure for the elastic limit is obtained. If now the material is subjected to repeated alternate tensile and compressive stresses and a short period of rest be allowed between the tests, it is found that the elastic limit falls to a figure considerably below that initially given. This figure Bauschinger refers to as the actual elastic limit of the material. Bauschinger further found that if the material be repeatedly stressed up to or above the elastic limit, it ruptures with a comparatively few repetitions of the load.

Repeated heating and cooling of a material has the effect of producing tensile and compressive stresses in the material, and should the material be subjected to largely varying temperatures it appears to me that Bauschinger's tests throw a considerable amount of light on the failures referred to by the author.

Another point the author has referred to, and one that has given rise to a great deal of discussion in the past, is the question of imposing a load of double the working pressure on boilers. In my own practice, dealing more particularly with land work, where there are no Board of Trade requirements to be met, I always specify for a test pressure in high pressure boilers of 100 pounds per square inch in excess of the working pressure, thus the test pressure for a boiler working at 160 pounds per square inch would be 260 pounds per square inch. In the case of old boilers I agree with the author that it is quite possible that the boilers may be strained when tested with a pressure of double the ordinary working pressure. In such cases it appears to me that one is running certain risks which are not necessary for the safety of the boiler.

I should just like to refer to one other point which, while it deals with the effect of temperature variation on a boiler, refers to land boilers rather than the marine type.

At the present time I have under my charge in an Electricity Supply Works some boilers which have only recently been constructed, and which, both as regards design and construction, are everything that one could wish for. In front of the boilers are two large doors, originally intended for the purpose of bringing coal in, but which at present are usually kept shut. At one side of the

building, however, there is a small door leading to the canal, and through this door coal is frequently taken in from the canal, and we invariably find that if the door has been open for any length of time that, owing to the cold air striking the boiler front—and we have a strong current of air at this point—the boiler begins to leak at the joint of the flues with the front end plate. I mention this simply as an illustration of the effect of variation in temperature on boilers. Mr. Miller

Mr. J. Reney Smith, in reply, said—Mr. Bruce first referred to the question of oil in furnaces. It is quite true, that it is very difficult, even with the very best filters, to entirely eliminate the question of oil, but I am assuming cases where we do eliminate the question of oil. I allow that it is quite possible that oil may help to cause these failures, but I will suggest, for your consideration in boiler designs, that there are reasons for producing these collapses other than oil, which we are not quite sure about. Mr. Smith

The casings which Mr. Bruce referred to is a matter which is undoubtedly now being considered much more than it was in the past, especially since some unfortunate experiences in connection with the recent transport work. Many of these steamers had to take coal given to them by the authorities very largely mixed with flaming coal, and these results which undoubtedly were occurring in a small way were very much exaggerated on these ships, with the result that there were frequent collapses of smoke box casings, and I think, after that experience, these are points that will be thoroughly considered when designs are submitted.

As to staying up the combustion chamber, these stays are jointed. They only allow for the support of the furnace, and offer no resistance to the vertical lift in the chamber.

Mr. Geddes rather criticised the suggestion as to the double working pressure test. Well, from what I have seen of this test, we ought not to quarrel with it, but I am quite sure that a little consideration will lead us to suppose that the suggestion has something to recommend it when we consider that we are replacing material equal to what we have removed, as a test of workmanship we have done all that is necessary without asking for an undue strain to be put on the other parts of the boiler.

Mr. Kemp also referred to oil and filters. With regard to these filters my experience has been this—they are better than nothing, "they take the thick out," but there is a certain amount of oil left in

Mr. Smith the feed water, and I do not think with mechanical filters that you can wholly eliminate that.

With respect to water tube boilers, I have not sufficient experience of them. I have sailed with them, and I prefer not to discuss them.

Mr. Collard referred to old boilers and said that the modern boiler is much less liable to defects than the old one, but what I rather referred to was that the old-fashioned plain furnace was less liable to distortion than the more modern one.

Mr. Blackburn also mentioned this question of forced draught. I think we are all agreed that forced draught, especially in the hands of an unskilful man, is a very dangerous system indeed.

Mr. Pain asked why oil should float and why it should attach itself to these furnaces. I think that is really a matter of density. Very largely it is carried through in the feed water and attacks the surface before it rises.

Mr. Wilson asks whether, in time, the whole of this expansion will not be concentrated on the part that has been fitted to take this expansion. Quite possibly; and it is only through experience that we will find out the difficulties of this; but I may say this, that vessels fitted, to my own knowledge, four years ago, with this type of furnace, have since given absolutely no trouble.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

ELEVENTH MEETING—23RD MARCH, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

The President and Members of the Manchester Section of the Institution of Electrical Engineers were present at this Meeting by invitation.

NOTES ON THE DESIGN OF ELECTRICAL MACHINERY.

BY LOUIS J. HUNT, ASSOC. M. INST. C.E., A.M.I.E.E.

So much has been written recently on the design of all classes of Electrical Machinery that the author feels some apology is necessary for presenting a paper to this Society on this subject. He has hoped, however, that some notes taken from everyday practice in the designing office may lead to discussion on various methods of predetermining the performance of electrical generators and motors. The paper is divided into two sections:—the first dealing with Continuous Current Machines, and the second part with Alternating Current Motors and Generators.

PART I.

CONTINUOUS CURRENT MACHINES.

It has often been suggested by various writers that a radical difference should be made in the designs of Continuous Current Machines between those built for working at 100 or 200 volts, and those intended for operating at 500 or 550 volts. From a

manufacturing point of view it is, of course, desirable to reduce the number of designs to a minimum in order to simplify standardization.

It will generally be found, especially when dealing with small sizes of machines, advantageous to use rather more copper on the armatures of low voltage machines than on those of generators and motors intended for working at higher voltages.

Generally speaking, in machines designed for working at 100 or 200 volts, it is quite easy to obtain thoroughly satisfactory commutation, the factor limiting the maximum output of such a machine being the rise in temperature of the armature. The case is different with dynamos and motors wound for working at a voltage of 500 volts or more. Here, generally, care has to be taken that the output is not limited by commutation troubles before the maximum output from the point of view of temperature rise has been reached.

In order to reduce the number of designs as much as possible it is advisable, at any rate, when dealing with small machines up to say 100 B.H.P., to design the armatures for 500 or 550 volts. It will then be quite easy to obtain excellent commutating qualities for all lower voltages.

If we design machines for 500 volts it will generally be found, especially for machines coming within the above-mentioned limits (100 B.H.P.), that it would be somewhat advantageous to use a larger total slot area for the lower voltage windings, which is tantamount to saying that machines wound for lower voltages can have stronger armatures than those wound for the highest voltages required.

As above stated, it is in the author's opinion, however, better to design small machines for the highest voltage required, on account of simplicity. In a given machine with a given value of magnetic flux the commutating qualities of an armature are inversely proportional to the volts per commutator part. It greatly simplifies shop work to use one size of commutator with one length of face for all voltages for small machines, and by suitably designing the armatures on the above lines this can be easily done.

For low voltage windings and very good commutating qualities soft quality carbon brushes may be used; for 200 volt windings a medium quality brush will give good results, and for high voltage commutators hard carbon brushes will ensure good commutation. There are, of course, a great many methods used by designers for predetermining the commutation qualities of a machine.

The following method has been used by the author for several years, and has been found to give very accurate results :—

Fig. 1 represents diagrammatically a two pole machine.

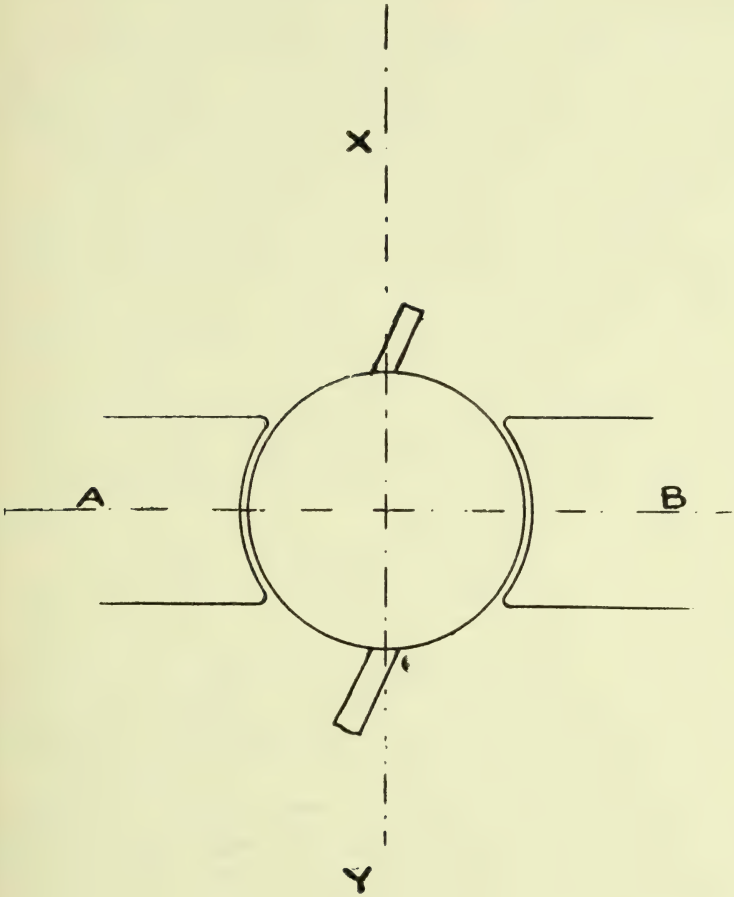


FIG. 1.

The line *A B* represents the axis of the main magnetic field, and the line *X Y* the axis of the armature field. We take this last field as the basis for determining whether a machine will commutate satisfactorily or not. We may treat the effect on the armature conductors of this field exactly in the same way as we treat the effect of the main flux on them, the only difference being that in the former case all we desire to know is the effect on the turns of wire between two commutator parts, whereas in the latter case it is the effect on the entire armature that we have to deal with.

Once we know the factors that must be taken into account to determine the relative value of the armature magnetic field, the whole problem becomes an exceedingly simple one. At first sight it may appear as if the diameter of the armature should be taken into account, but after carefully investigating the subject it seems that we need only consider the armature ampere-turns per pole, and the length of the armature core, in order to arrive at a satisfactory basis for calculation.

The tendency to sparking may then be said to be proportional to the armature ampere-turns per pole, the number of turns per commutator part, the speed of the machine in revolutions per minute and the length of core.

Writing δ to represent a figure denoting the tendency of a machine to spark.

$$\delta = ATp. \times T \times L \times R \times K \times \frac{P}{4.}$$

Where $A\ Tp$ = Armature ampere turns per pole.

T = Armature turns per commutator part.

R = Revolutions per minute at which the armature is running.

L = Gross length of armature core in inches.

K = 1 for lap wound armatures and $\frac{p}{2}$ for wave wound ones.

P = Number of poles of machine.

After examination of a large number of machines the author has found that the above formula holds good for machines of all sizes, and has not found any correction necessary for abnormal conditions.

For slotted armatures δ may be given a limiting value of 60×10^6, and a figure as high as 80×10^6 will give sparkless commutation if a hard quality carbon brush be used, and a large brush lead is not objected to. The author prefers to limit δ to 50×10^6—60×10^6, which with "S" quality carbon brushes as made by the Le Carbone Company will give perfectly sparkless commutation with fixed position of the brushes.

If the sparking figure be kept within the above limits, one need not trouble about the ratio of air gap ampere turns to armature ampere turns in order to ensure a fixed brush lead; in fact, with properly shaped pole tips one may reduce the length of the air gap to that necessary mechanically, without in any way changing the commutating qualities of a machine.

A small four pole dynamo was experimented upon some time since with a view to testing these ideas, and though the tests were not

carried out very thoroughly yet the results obtained may be of interest.

The machine had an armature 13 inches diameter. There were three turns on the armature per commutator part, and the winding was a wave one.

It was separately excited and driven by belt, the load consisting of the usual test room resistances. The field coils were first excited with the normal current, and the armature was run up to a speed of 820 revolutions per minute. The current through the armature was 38 amperes and the voltage across the brushes 500 volts. The number of armature ampere turns per pole with this current through the windings was 1985. Length of armature core 8·25 inches. From this data δ was found as follows :—

$$\delta = 1985 \times 3 \times 820 \times 8{\cdot}25 \times 2 = 80{\cdot}6 \times 10^6.$$

The magnetic flux per pole was $2{\cdot}18 \times 10^6$ lines, and this field required 2,240 ampere turns per pole to drive it across the air gap and through the slots. The ratio between ampere turns required for one air gap + teeth and armature ampere turns per pole, was therefore 1·13.

$$\frac{\text{(gap + teeth) ampere turns}}{ATp.} = 1{\cdot}13.$$

With 38 amperes through the armature the commutation was found to be very poor, the brushes being very sensitive and sparking badly unless shifted, when the load was varied.

A sparkless position could be found for all loads, but it was impossible to run with fixed lead. The brushes were of "S" quality, Le Carbone make.

Resistances were next inserted in the field circuit, and the shunt current reduced to ·5 ampere. The current through the armature was kept at 38 amperes, as in the previous test, and the machine was run up to a speed of 500 revolutions per minute. The magnetic flux per pole was $1{\cdot}24 \times 10^6$. The sparking figure was therefore—

$$\delta = 1985 \times 3 \times 500 \times 8{\cdot}25 \times 2 = 49{\cdot}2 \times 10^6.$$

The commutation qualities of the machine were now found to be excellent, and the brushes were not at all sensitive. With a fixed load of 38 amperes through the armature, the brushes could be rocked round the commutator through a wide angle without showing any signs of sparking, and with fixed brush lead sparkless commutation was obtained with a load varying from open circuit to about 50 amperes. The current was not increased beyond this load. The air gap + teeth ampere turns required for this value of flux was 1180,

therefore the ratio between the armature ampere turns and the air gap + teeth ampere turns was :—

$$\frac{1180}{1985} = \cdot 595.$$

Some further tests bearing on the question of the effect of the ratio between field ampere turns and armature ampere turns were carried out a few days ago in order to obtain some further data for this paper, and the results of the tests are appended.

The machine was a four pole generator, manufactured by The Sandycroft Foundry Co., Ltd., of Chester, designed for a load of 75 K.W. at 210 volts when driven at a speed of 480 revolutions per minute.

The full load current was therefore 357 amperes, the armature current being 363 amperes.

The following are the particulars of the machine :—

Length of core ... ... inches	$11\frac{1}{4}$
Number of conductors on armature	392
Number of commutator parts	196
Turns per " "	1
Type of armature winding	lap

The commutator of this machine would run absolutely sparklessly under any conditions of the test with the brushes on the neutral points. The brushes were rocked in order to determine at what lead, backward and forward, the commutator would show the first trace of sparking.

The brushes used on the test were of "Z" quality, the contact density being 40·3 amperes per square inch, with a load of 300 amperes.

In designing continuous current machines, δ makes a very good starting point taken in conjunction with the maximum number of commutator parts it is mechanically practicable to use.

We may deduce some useful formula from δ—

$$\delta = ATp. \quad TLRK \frac{P}{4.}$$

$$\text{but } T = \frac{60 \times 10^8 \times E.}{2 \; FRYK.}$$

where E = Internal E.M.F. of armature.

F = Magnetic flux per pole.

Y = Number of parts in commutator.

$$TR = \frac{30 \times 10^8 \times E.}{FYK.}$$

$$\delta = \frac{75 \times 10^7 \times ATp. \; LEP.}{FY.}$$

Test on "Sandycroft" 4 pole 75 K.W. Dynamo.

Volts	Amperes	Field current	$\frac{A T_G}{A T_P}$	R.P.M.	$\delta \times 10^{-6}$	REMARKS
		Amperes.				
145	300	2·3	·82	475	19·7	Absolutely sparkless, Brushes on neutral point
115	300	1·5	·57	550	22·8	Do., do., do.
50	300	·5	·26	580	24·0	Do., do., do.
12·5	200	—	·14	600	16·6	Do., do., do.
15·0	290	—	·11	580	23·3	Do., Brushes on 1·8° backward lead
15·0	300	—	·11	580	24·1	Barely visible sparking, 5·5° backward lead
50·0	280	—	·28	580	22·4	Do., 7·28° do.
20·0	300	·3	·13	560	23·3	Absolutely sparkless, Brushes on neutral point
16·5	300	·2	·12	560	23·3	Do., do. do.
20·0	300	·2	·13	560	23·3	Do., Brushes on 8·2° backward lead
20·0	280	·2	·14	560	21·7	Occasional sparking, 11·8° backward lead
30·0	290	·3	·19	560	22·5	Do., 11·8° do.
40·0	280	·4	·24	560	21·7	Do., 11·8° do.
50·0	300	·5	·18	560	23·3	Absolutely sparkless, 2·3° forward lead
34·0	300	·5	·2	550	17·8	Do., 2·3° do.
12·0	235	·2	·13	560	18·2	Do., 2·3° do.
13·0	250	·2	·1	680*	23·5	Do., 2·3° do.
5·0	210	·2	·096	560	16·2	Do., 5·9° do.

* Vibration prevented speed being increased above this point. Machine way on temporary foundations.

AT_G = Air Gap Ampere turns.

For a given machine $\frac{ATp}{F}$ will be about constant, therefore the tendency to sparking will be proportional to the volts per commutator part.

Let Ec = Volts per commutator part.

$$Ec = \frac{PE.}{Y}$$

P = Number of Magnet Poles.

Then the maximum permissible number of volts per part for a given value of δ will be given by—

$$\text{Max } Ec = \frac{F\ \delta}{75 \times 10^7\ ATp\ L.} \qquad \text{(i.)}$$

$$\text{taking } \delta = 60 \times 10^6$$

$$\text{Max } Ec = \frac{F}{12{\cdot}5\ L\ ATp.}$$

For an armature of a given diameter and length the capacity of the machine in Watts per revolution will be fairly closely known to a designer. For the Watts generated by an armature we may write—

$$\text{Watts} = \frac{N\ F\ R\ A}{60 \times 10^8}$$

Where N = Total number of conductors on the armature.

A = Current of machines.

$$ATp = \frac{N\ A}{2p^2.} \text{ for a lap wound machine.}$$

$$\therefore \text{Watts} = \frac{p^2\ ATp\ F\ R}{30 \times 10^8}$$

$$\therefore ATp\ F = \frac{30 \times 10^8\ W.}{p^2\ R.} \qquad \text{(ii.)}$$

Where W = Watts generated by armature.

$$\text{From equation (i.) } F = \frac{75 \times 10^7\ Ec\ ATp\ L.}{\delta.}$$

$$\text{From equation (ii.) } F = \frac{30 \times 10^8\ W.}{p^2\ R\ ATp.} = \frac{30 \times 10^8\ Wr.}{p^2\ ATp.}$$

Where Wr = Watts per revolution.

From these equations can be found the maximum permissible number of armature ampere turns per pole for a given value of δ.

$$\text{Max } ATp = \frac{2}{P}\sqrt{\frac{\delta\ Wr}{Ec\ L.}}$$

It has been found that for values of δ of 50×10^6 to 60×10^6 or thereabouts, carbon brushes of "S" quality will give excellent results. For values of 25×10^6—40×10^6 or thereabouts, "Z" quality brushes are preferred, and for values 20×10^6 and

less, "X" quality brushes will ensure perfectly good commutation. The author has recently used the last mentioned quality brushes on a 100 volt generator where δ came out at 18×10^6, the contact density of the brushes being about 80 amperes per square inch. The result was excellent. The brushes mentioned above are of the Le Carbone Co.'s make.

COMMUTATOR LOSSES.

Consulting Engineers often specify a maximum value for the current density at the contacts of carbon brushes and commutator irrespective of the voltage and speed at which a machine may be running. This often results in the commutator losses being greater than need be. Investigations into tests of contact resistances of carbon brushes will show that for any given peripheral speed at which a commutator may be running there will be a certain current density at the contacts of the brushes which will give a minimum value to the commutator losses.

For brushes of the above-mentioned make the contact resistance per square inch is approximately as follows:—

For "S" quality brushes for densities of 20 amperes per square inch or above

$$\cdot 187 \sqrt{\frac{1}{D}}$$

For "Z" quality brushes for densities of 40 amperes and above:—

$$\cdot 09 \sqrt{\frac{1}{D}}$$

Where D = current density in amperes per square inch. The contact resistance of "X" quality brushes appears to vary a good deal more than either of the other qualities with the pressure applied to the brushes. It may be considerably reduced by increasing the pressure on the brushes, and it will generally be found that the pressure must be considerably greater than is usual with "S" and "Z" quality brushes in order to benefit very much by their use. The gain in reduction of contact resistance by increased pressure of the springs will be a good deal more than the increased loss due to friction.

Dealing first with "Z" type brushes, and taking the pressure applied to the brushes at 20 ounces per square inch and the coefficient of friction at ·3:—

Tangential pull per square inch = ·375 pounds.

The Watts lost due to friction will be:—

Friction Watts per square inch ... = $\cdot 0085\, p$

Where p = peripheral speed in feet per minute at surface of commutator.

The total Watts lost per square inch of contact surface, *i.e.* ($C^2 R$ + friction) Watts will be

(iii.) Total Watts per square inch $= \cdot 09\, D^{\frac{3}{2}} + \cdot 0085\, p$.

If C be the total armature current :—

$$\text{Total contact surface} = \frac{2C}{D}$$

$$\therefore \text{ Total Watts lost} = W = C\,(\cdot 18\, D^{\frac{1}{2}} + \cdot 017\, p\, D^{-1})$$

Differentiating W with regard to D and equating to zero :—

$$\cdot 09\, D^{-\frac{1}{2}} = \cdot 017\, p^{-2} \cdot \frac{d\,W}{d\,D} = \cdot 09\, D^{-\frac{1}{2}} - \cdot 017\, p^{-2}$$

(iv.) $\therefore \quad D^{\frac{3}{2}} = \cdot 189\, p$

$\therefore$ Density for minimum losses $= \cdot 33\, p^{\frac{2}{3}}$.

From equation (iii.) $C^2 R$ loss per square inch $= \cdot 09\, D^{\frac{3}{2}}$; but $D^{\frac{3}{2}} = \cdot 189\, p$.

$\therefore \quad C^2 R$ loss per square inch $= \cdot 09\, D^{\frac{3}{2}} = \cdot 17\, p$.

From (iii.) Friction loss per square inch $= \cdot 085\, p$.

We therefore see that in order to reduce the commutator losses to a minimum the contact surface of the brushes should be so chosen that the loss due to friction is half that due to $C^2 R$ at the contacts.

It can be shown in the same way that the total Watts lost per square inch at contact surfaces of "S" quality carbon brushes :—

$$= \cdot 187\, D^{\frac{3}{2}} + \cdot 0085\, p$$

$$\text{Total Watts lost} = C\,(\cdot 374\, D^{\frac{1}{2}} + \cdot 017\, P\, D^{-1}).$$

From this we deduce as before a value of D for minimum commutator losses.

$$D = \cdot 202\, p^{\frac{3}{2}}$$

And, as before, this shows that for minimum losses the loss due to friction should be half that due to $C^2 R$ loss.

Part II.

ALTERNATING CURRENT MACHINES.

There still exists a difference of opinion among writers on the subject of alternating current machine design as to the value of the resultant magnetising ampere turns produced by the magnetising currents flowing in the several windings of a polyphase machine.

According to some authorities, if the magnetising current flowing through the windings of one phase of a three-phase machine produces x ampere turns, then the resultant ampere turns of the three phases

will be $2x$, while, according to other writers, the resultant ampere turns will be $1{\cdot}5x$. This matter is, of course, of the greatest importance in dealing with the subject of the design of all classes of alternating current machines, as it is the resultant ampere turns with which one has to deal when calculating the demagnetising effect of the armature of a generator, or the rotor of an induction motor. Again, in considering the magnetising current required by an induction motor in order to produce the necessary ampere turns in the stator windings, it will make a considerable difference to the calculations if we consider that each phase will have to supply half the necessary ampere turns instead of three quarters of them.

In order to further emphasize the importance of a clear understanding as to the resultant ampere turns, it may be pointed out that the voltage regulation of a generator depends more upon the demagnetising effect of the armature than upon the inductance of its windings. Again, the performance of an induction motor as regards its power factor and maximum torque depends upon the demagnetising effect of the rotor windings, though in this case, of course, without the inductance of the stator and rotor windings there would exist no demagnetising effect, whereas in a generator, if the windings be imagined to be non-inductive, an external inductive load will produce a demagnetising current in the armature windings.

It has been very clearly shown by Eborall, by means of a Vector diagram, that the resultant magnetising force in a three-phase armature is equal to 1·5 times the magnetising force of one phase. It can also be proved analytically that this is the case, and the fact that on this basis it is possible to calculate the no-load current of an induction motor with great accuracy is probably the best proof of all.

INDUCTANCE OF WINDINGS.

In considering the inductance of windings of alternating current machines, it is only necessary to treat of windings embedded in slots or holes, as coreless windings are only used at the present time, if at all, for very special purposes. A large amount of data has been published of tests of windings embedded in slots of various shapes and sizes in terms of the leakage flux per ampere turn per inch length of core. Such tests can be easily carried out in the test-room and by comparing cores having the same number of slots and arrangement of windings, but of different axial lengths, it is possible to separate the flux produced by the conductors imbedded in the iron and that due to the currents flowing in the end connections.

The inductance of a coil will, of course, vary with its position relative to the field magnets, and very different results are obtained when slots containing conductors are situate directly under a magnetic pole or when midway between two adjacent poles. If tests are first made with the field magnets unexcited and afterwards the magnet poles be brought to a high degree of saturation by exciting the field windings, different results are again obtained, the inductance of the windings in the latter test being much less than in the former.

The question of the synchronous inductance is a very knotty one, and it is often suggested that a mean value should be taken for the inductance used in calculations between that existing when a coil is directly under a magnet pole and the inductance of the coil when midway between two adjacent poles. The author, a few years ago, examined the voltage regulation tests of several alternators, taking this mean value for the inductance of the windings. He found in all cases that this value was too high, and that in order to bring the calculations and performance of a machine into agreement the minimum value should be taken. This conclusion has received abundant confirmation since that time, and it has been found that by working on these lines, and taking the resultant ampere turns of a three-phase winding at 1·5 times, those of one-phase, the voltage regulation of an alternator or the power factor and maximum overload of an induction motor can be calculated very closely.

In carrying out inductance tests then, it is only necessary to make the tests on the armature when removed from its magnet system if the machine be an alternating current generator of the synchronous type. When dealing with induction motors the rotor should first be removed from the stator and separate tests carried out on the windings of each.

When making inductance tests on windings having but a few turns per coil, the potential difference required is often very small. The resistance of the contacts may then easily lead to considerable error, and it is therefore advisable to use a method of calculating L from the test readings, not requiring an accurate knowledge of the resistance of the circuit. The following formula is a good one to use :—

$$pL = \frac{\sqrt{(\text{Apparent Watts})^2 - (\text{True Watts})^2}}{C^2}$$

When $p = 2\pi \sim$.

L = Coefficient of self induction in henries.

C = Current in the winding.

If L be found by means of tests, the leakage flux per ampere turn can of course be found by multiplying by 10^8 and dividing by S^2, S being the number of turns in the coil under test. It is sometimes stated that this flux represents the leakage flux per R.M.S. ampere turn. There appears to be some confusion here, as if the coefficient of self-induction L be analyzed it would appear that $\frac{L \times 10^8}{S^2}$ equals the leakage flux per maximum ampere turn, thus :—

$$L = \frac{\cdot 4\, \pi\, A\, \upsilon\, S^2}{l \times 10^8} \qquad \text{(i.)}$$

Where A = the cross section of the magnetic path in square centimetres.

υ = the permeability of the iron.

S = the number of turns per coil.

l = the length of the magnetic path in centimetres.

The magnetic flux in a circuit is given by the formula :—

$$\text{Flux} = \frac{\cdot 4\, \pi\, A\, \upsilon\, S.\ C\ \text{max.}}{l}$$

$$\text{Substituting in (i.) } L = \frac{\text{Flux } S.}{10^8\ C\ \text{max.}}$$

Where C max. = the maximum value of the alternating current.

$$\therefore \text{ Flux per } A\ T \text{ max.} = \frac{L \times 10^8}{S^2}$$

$A\ T$ max. = the number of turns in the coil multiplied by the maximum value of the current.

SYNCHRONOUS GENERATORS.

The predetermination of the voltage regulation of an alternating current generator is an exceedingly interesting problem, and in a general paper like the present one, consisting of a few rough notes, it is impossible to go fully into the theory of the subject.

Modern alternators are always designed to work well above the straight line portion of the characteristic curve of the machine in order to improve the voltage regulation, unless they are required for some special service where close regulation is undesirable. If an alternator be on load a component of the armature current will produce demagnetising ampere turns, and these will reduce the main flux. E, the internal E.M.F. of the machine, is proportional to this flux and will be correspondingly reduced. For this reason, if it is a question of finding the terminal *P.D.*, it greatly simplifies the problem if we start the calculation with known values of field ampere turns and demagnetising component C_2. The effective ampere turns are then easily obtained and the internal E.M.F. of the generator is at once known.

As the demagnetising effect of the armature windings play so large a part in bringing about the drop in the terminal voltage it may be as well to briefly define what is meant by the demagnetising current. If a machine could be provided with armature windings having no inductance, the current and E.M.F. throughout the entire circuit would be in phase if the generator were working upon a non-inductive load, and the armature windings would produce no demagnetising effect upon the field circuit. This is an impossible case, of course, as self-induction must be present in any armature, and so there must always be a demagnetising effect as long as the windings carry current. If we take the actual internal E.M.F. of the machine generated by the magnet system as the starting point, then it will be the component of the armature current lagging 90 degrees behind this E.M.F. which will represent the demagnetising current. The component of the armature current in phase with the internal E.M.F. will have no demagnetising effect but will increase the magnetic density of one-half of the pole face of a magnet pole and decrease the density of the other half. The voltage regulation is not perceptibly effected by this. The internal E.M.F. referred to above is the E.M.F. which would be generated by the machine if running upon open circuit with the same number of field ampere turns. We will call this E.M.F. $= E$. The simplest way to attack the problem is to first fix the value of the field ampere turns, and then to take various values for C_2, the demagnetising component of the armature current :—

Let $p = 2\pi \sim$

L_G = the Coefficient of self induction of the armature windings in henries.

NON-INDUCTIVE LOAD.

For the sake of simplicity we will first consider the case of an alternator running on a non-inductive load.

Having fixed the number of field ampere turns, a value may be taken for C_2 and from this the demagnetising ampere turns are at once obtained. Deducting these from the field ampere turns leaves the nett or effective ampere turns, and referring to the magnetic characteristic curve of the machine, E is obtained.

Having definitely fixed the values of E, C_2 and pL_G, it will be obvious that both C the current in the circuit and R the total resistance of the circuit are fixed. C can be obtained from the following formula:— $C = \sqrt{\frac{C_2 E}{p L}}$

Knowing C and C_2, there are several ways of finding R the resistance of the external circuit + armature windings.

The following equation is probably as simple as any :—

$$R = \sqrt{\frac{E^2 - p^2 L^2 C_2}{C}}$$

Let R_G equal the resistance of the generator armature windings. Then deducting this from R the total ohmic resistance of the circuit leaves R_E the resistance of the non-inductive load. This gives the $P.D.$ at the alternator terminals,

$$P.D. = C.R._E$$

If we now take the same number of field ampere turns as before and consider the machine running on open circuit, and consequently without any armature reaction, E can be obtained from the no-load characteristic curve. On open circuit $E = P.D.$ From this the voltage regulation for a current C is known.

TO FIND FIELD AMPERE TURNS FOR CONSTANT P.D.

Still dealing with a generator working upon a non-inductive load, it is required to know the number of field ampere turns necessary in order to keep the terminal potential difference constant for various values of current C.

$$\text{Let } E_T = P.D. \text{ at terminals.}$$
$$C = \text{Current.}$$
$$\text{then } R_E = \frac{E_T}{C}$$
$$pL = pL_E + pL_G = pL_G$$
$$R = R_E + R_G$$

From this data we can find C_2 from the equation :—

$$C_2 = \frac{pLC}{\sqrt{(R^2 + p^2 L^2)}}$$

Returning to the equation :—

$$C = \sqrt{\frac{C_2 E}{pL_G}}$$
$$E = \frac{pL_G C^2}{C_2}$$

E being the internal E.M.F. of the generator, the number of field ampere turns required can be obtained directly from the no-load characteristic curve of the machine. To these must be added the demagnetising ampere turns of the armature winding equal to, in a single phase machine, C_2 multiplied by the number of armature turns per pole.

If C represents the full load current of the generator then as $P.D = E$ on no load, the open circuit $P.D$ with the same number

of field ampere turns can be obtained from the characteristic curve, and the rise in terminal voltage calculated.

A two-phase alternator can be worked out in exactly the same way; E and $P\,D$ being the internal E.M.F. and potential difference respectively, and C the current per phase; C_2 the demagnetising current per phase multiplied by the armature ampere turns per pole equals the demagnetising ampere turns per field pole.

In a three-phase generator E and $P\,D$ represent the internal E.M.F. and terminal potential difference per phase, and C_2 the demagnetising current per phase. The demagnetising ampere turns per field pole equals $1{\cdot}5\ C_2\ T$. Where T = the armature turns per pole and per phase. In working out a three-phase machine it is only necessary to deal with one phase, the ohmic resistance and self induction being, of course, taken for one phase only.

REGULATION ON INDUCTIVE LOADS.

As for a machine working on a non-inductive load it is simplest to take the field ampere turns per pole as the basis for calculations. We require to plot a curve, the ordinates of which represent the terminal $P.D$, and the abscissæ, the current; the power factor of the external circuit being known. This is not quite such a simple problem as the non-inductive load one, as both R and pL are now unknown quantities. As in the previous case it is best to take various values of C_2, and then to work out the terminal $P.D$ and the current in each case.

The demagnetising ampere turns are now calculated from C_2 and the number of armature turns per pole, and deducting these from the field ampere turns per pole leaves the nett number available. The internal E.M.F. = E is found for the nett number of ampere turns from the characteristic curve of the machine. E and C_2 being known, there are several ways of finding R, the total ohmic resistance of the external circuit and the armature. It may be calculated from the equation:—

$$C_2 = \frac{pLE}{p^2L^2 + R^2}$$

Using the same symbols as before:—

$$pL_E = R_E \tan \phi$$

Where $Cos.\ \phi$ equals the power factor of the external circuit:—

$$R = R_G + R_E$$

$$pL = pL_G + pL_E$$

$$C = \frac{E}{\sqrt{(R^2 + p^2 L^2)}}$$

$$P\,D = C\ \sqrt{R^{E\,2} + p^2 L_E{}^2}$$

TO FIND AMPERE TURNS FOR CONSTANT P.D.

Using the same symbols as before :—

$$\sqrt{R_E^2 + p^2 L_E^2} = \frac{E_T}{C}$$

$$pL_E = R_E \tan \phi$$

Where *Cos.* ϕ equals the power factor of the external circuit :—

$$\therefore \quad R_E = \frac{E_T}{C \sqrt{(1 + \tan^2 \phi)}}$$

From this data R and pL can be obtained, pL_G and R_G being of course known.

C_2 can now be found by the same equation as used in the case of a machine working on a non-inductive load.

$$C_2 = \frac{pL\ C}{\sqrt{(R^2 + p^2 L^2)}}$$

$$E = \frac{pLC^2}{C_2}$$

The field ampere turns per pole are read direct from the no-load characteristic curve, and these plus the demagnetising ampere turns ($C_2\ T$) equal the gross number of ampere turns required per field pole.

Though, of course, both the E.M.F. and current waves are assumed in this method to follow the sine law, the error thus introduced does not seem to be of importance. Tests on machines in the shops have shown results agreeing very closely with the figures obtained on the above system.

The values of E, C and C_2 in the above equations are R.M.S. ones, but when determining the demagnetising ampere turns the maximum value of C_2 must of course be taken.

In order to make the method quite clear a machine has been worked out with a view to determining the voltage regulation when running on (*a*) full non-inductive load, (*b*) full inductive load of which the power factor is ·8.

The generator is a single phase one, the following being the essential particulars :—

P D at full load	...	=	2000 volts.
Full load current	...	=	100 amperes.
R_G	...	=	·4 ohms.
pL_G	...	=	3·2
Armature turns per pole		=	6

The no-load characteristic curve is represented by Fig. 2.

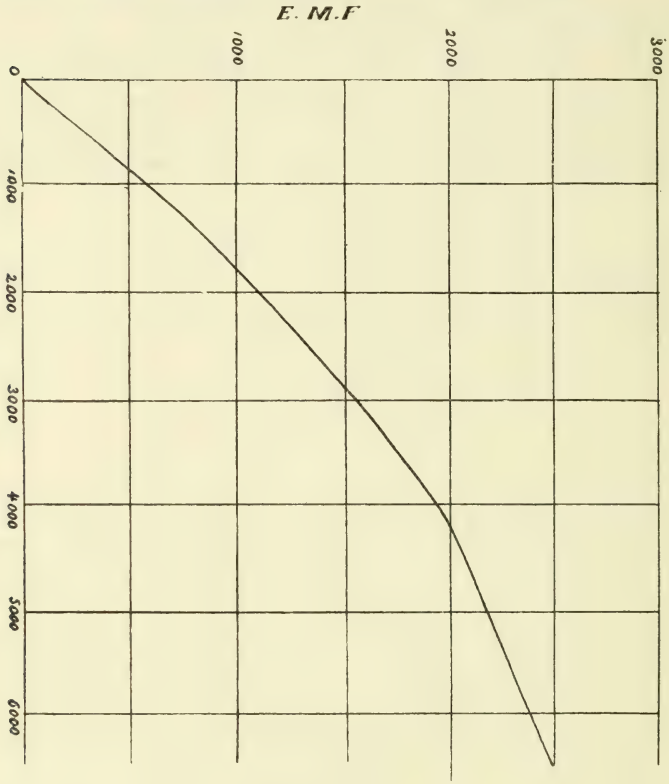


FIG. 2.

The requirements are that we shall determine the rise in terminal voltage when full load current is thrown off the machine, the field excitation having been adjusted to give 2000 volts on full load.

Condition (a) Non-inductive load :—

$$R_E = \frac{2000}{100} = 20 \text{ ohms.}$$

$$\therefore \quad R = 20{\cdot}4 \text{ ohms.}$$

$$C_2 = \frac{p L_G \; C}{\sqrt{(R^2 + p^2 \; L_G{}^2)}}$$

$$= \frac{320}{20{\cdot}6} = 15{\cdot}52 \text{ amperes.}$$

$$E = \frac{p L_G C^2}{C_2} = 2060 \text{ volts.}$$

Fig. 2 represents the no-load characteristic curve of the machine,

and from it the number of ampere turns required per field pole for 2060 volts is found to be 4340.

Nett amperes turns	=	4340
Demagnetising ampere turns = 1·414 × 15·52 × 6 =		132
Gross ampere turns	=	4472

Again, referring to Fig. 2, we find that with this number of ampere turns per field pole, the machine on open circuit would generate 2095 volts. The rise in terminal *P.D* on throwing off a non-inductive load of 100 amperes would therefore be 95 volts or 4·75 per cent.

From the curve it will be seen that the machine would require 4140 ampere turns per pole for it to generate 2000 volts on open circuit, therefore the exciting current would have to be increased 8 per cent. in order to bring the *P.D* up to 2000 volts with a load of 100 amperes.

Condition (b) Inductive load :—

C = 100 amperes. $P.F$ of external circuit = ·8.

As for a non-inductive load, it is first necessary to determine the number of field ampere turns for the machine running under full load conditions.

$$R_E = \frac{E_T}{C\sqrt{(1 + tan^2\ \phi)}}$$

$$Cos.\ \phi = \cdot 8\ \therefore\ tan\ \phi = \cdot 75.$$

$$\therefore\ R_E = \frac{2000}{100 \times 1\cdot 25} = 16 \text{ ohms.}$$

$$pL_E = 12$$

$$\therefore\ R = 16\cdot 4 \text{ ohms.}$$

$$pL = 15\cdot 2 \text{ "}$$

$$C_2 = \frac{pL\ C}{\sqrt{(R^2 + p^2\ L^2)}} = \frac{1520}{22\cdot 36}$$

$$= 68 \text{ amperes}$$

$$E = \frac{pLC^2}{C_2} = 2236 \text{ volts.}$$

From Fig. 2 the number of field ampere turns required for this load is found to be 5120.

Nett $A\ T$	=	5,120
Demagnetising $A\ T$ = 1·414 × 68 × 6 ...	=	576
Gross $A\ T$	=	5,696

On throwing off the load the machine on open circuit will generate with this number of field ampere turns 2350 volts. The terminal *P.D* will therefore rise 350 volts or 17·5 per cent.

$A.T$ required for 100 amperes	=	5696
$A.T$ " on open circuit	=	4140
Increase...	=	1556 or 37·6 per cent.

That is to say, the field ampere-turns must be increased 37·6 per cent. between no load and full load for a constant terminal voltage of 2000 volts.

POLYPHASE INDUCTION MOTORS.

As already remarked it is impossible in a general paper to consider thoroughly the theory of any one class of machine, but it may be of some interest to examine very briefly the manner in which the various properties of an induction motor act upon one another, and how the performance of the machine is influenced by them.

The value of the power factor and the overload capacity of a motor is almost entirely governed by the demagnetising component of the rotor current. At no load this is practically nil, but as the torque is increased it grows with it, slowly at first until the load is reached at which the power factor of the machine has its highest value. After this load has been passed, the rotor demagnetising component increases more rapidly, until, when the motor is developing its maximum torque, it attains the same value as the component of the rotor current with which it is in quadrature.

This demagnetising current depends upon three things: (*a*) The coefficient of leakage of the stator windings; (*b*) the coefficient of leakage of the rotor windings; (*c*) the ohmic resistance of the stator windings. Instead of using coefficients of leakage the author finds it simpler to work out the coefficient of mutual induction between the stator and rotor windings, and then to estimate the coefficients of self-induction of the stator and rotor windings.

First, let it be assumed that the stator windings are non-inductive and possess no ohmic resistance. The rotor lagging current can be calculated by the ordinary method as applied to any circuit possessing both inductance and resistance, the periodicity of course depending upon the slip of the rotor. It will be obvious that the resistance of the rotor windings will not affect the lagging rotor currents, as the periodicity of the currents would be increased with any increase of the rotor resistance owing to the greater slip necessary. If we now consider a motor, both the stator and the rotor windings of which possess inductance, the conditions are changed. The stator winding is still supposed to have no resistance. The inductance of the stator winding has to be neutralized in the motor itself, and this is effected by a magnetic field, which is linked with both stator and rotor windings, and though it neutralizes the stator inductance, it unfortunately increases the lagging current in the rotor windings.

Finally, let the stator windings possess resistance as well as inductance. Now the rotor is to a certain extent shielded from the stator

inductance by the resistance of the stator windings which assists in neutralizing the inductance. The neutralizing flux is consequently reduced and with it the demagnetising component of the rotor current.

In order to show more clearly the effect of the demagnetising component of the rotor current upon the performance of a motor, a small machine has been worked out, and values of power factor, slip and demagnetising rotor currents, have been tabulated. The machine is a standard three-phase induction motor built by The Sandycroft Foundry Co., Limited, and the stator motor stampings are shown diagrammatically in Fig. 3.

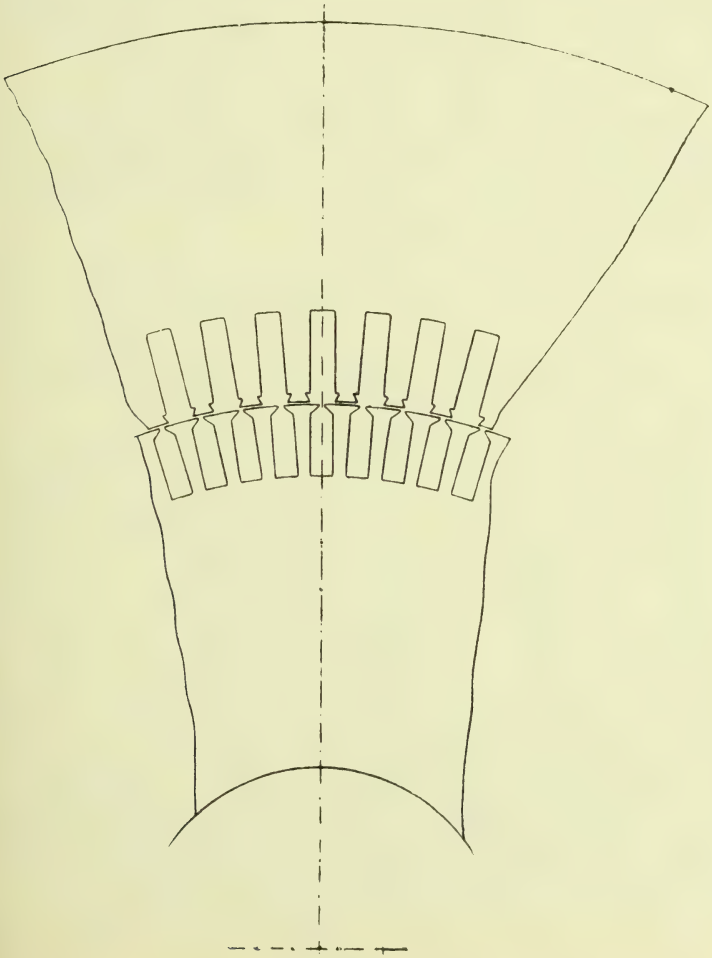


FIG. 3.

The following are the particulars :—

Full load...	20 B.H.P.
Synchronous speed	750 R.P.M.
Voltage between terminals	220
Periodicity	25 ∿ per sec.
Outside diameter of stator	$25\frac{1}{2}$ inches
Bore stator	$15\frac{1}{16}$ inches
Gross axial length of stator and rotor ...	7 inches
Type of stator slots	open
Number of stator slots	72
Wires per stator	6
Type of rotor slots	Open $\frac{1}{16}$-inch at periphery
Number of rotor slots	84
Wires per rotor slot	2

In working out the following particulars, the ratio between the number of stator and rotor turns has been considered as unity. This, of course, does not affect the results obtained, as the number of ampere turns will not be altered in any way.

Torque, lbs. ft.	Slip of Rotor	Stator magnetising current	Rotor demagnetising current	Power Factor
	Per cent.	Amperes	Amperes	Per cent.
36·2	1·1	12	·32	64·1
67·5	1·85	12·8	1·22	84·1
100·5	2·7	14·2	2·75	90·4
146	4·1	18·2	7·0	92·6
189	5·96	23·2	12·57	93·2
227	7·05	28·1	17·22	92·8
282	9·65	40·15	29·8	91·25
356	13·05	59·2	48·5	88·5
386	15·2	75·0	65·6	86·1
400	22·2	109	100·4	79

In conclusion, the author would like to express his thanks to Messrs. The Sandycroft Foundry Co., Limited, for permitting the use for illustrative purposes of data and tests relating to machines of their manufacture, and also to Mr. Edward Comerford for carrying out the tests and for his assistance generally.

DISCUSSION.

Mr. EUSTACE THOMAS said—I have been greatly interested in the calculation of the commutating properties of direct current machines, and seven years ago examined from this point of view the design of a large numbers of generators from 4 or 5 K.W. to 1500 K.W. capacity, all of which had been built and had their behaviour recorded. At that time it was generally supposed that commutation required a "Reversing Field," and text books were full of absurd rules about armature reaction, since proved by hundreds of successful machines to be altogether fallacious. I pointed out the true explanation, and the effect of the brushes, in an article to the "Electrician," and wrote down a differential equation to express these parts, but could not get a solution of practical use worked out direct from this, as all attempts resulted in diverging series. No complete expression exists at the present day, but in America a method of calculating the effect of the inductance of the coil in causing sparking was adopted, based, I believe, on some previous work of Swinburne's. This, in a more developed form, is fully described in Hobart's articles in "Traction and Transmission." Mr. Thomas

From experience I believe these methods to be the best for calculating liability to sparking, but they are still imperfect and require to be used with judgment. They treat commutating troubles as due to the inductance of the coil under commutation, and calculate the "Resistance Voltage" (a quite fictitious value, but of relative use) necessary to effect reversal.

The effect of cross armature reaction as described by the author of the paper under discussion undoubtedly comes in also, however, and I was led to this conclusion some time back. The author's formula, however, appears to be incorrect. In the first place, the effect is due to the rate of cutting Lines of Force, and this requires in his formula, not the Revolution per minute, but the *peripheral* speed. In the second place, p^2 per wave wound armatures assumes only two sets of brushes, or omits the effect of having p sets of brushes, and this is scarcely correct. It is an odd thing, however, that his formula, taken as he puts it, contains all the essential variable of the Reactance Voltage method, and in the same relation, if one uses p_2 throughout, and assumes that the brushes always cover the same number of segments, and that all slots are alike. Hence, I

Mr. Thomas believe his formula may often give fairly good results, although it does not express at all what he intended, and is incomplete in not taking into account the form of slot, number of segments covered by brush, &c.

Some rough calculations show that machines of different designs would require quite different armatures using the author's formula. Thus one machine worked well with a constant of about 80. Another was not absolutely first rate with 53. A third with 26 could with advantage have a little movement of the brushes from no load to full load.

It would be very interesting to examine the relative importance of the cross field due to armature reaction. This could be done as follows:—An armature could be run by a belt or otherwise in an unexcited field, and current led in by one brush and out by another quite close to it. In this case there would be practically no armature reaction. The experiment could then be repeated with the brushes in their ordinary positions, when armature reaction would come in. The currents would be noted at which sparks occurred.

The author's formula for brush losses would be affected by variation of peripheral speed and current density. Both of these greatly affect the apparent contact resistance.

I should be interested to see if it would be practical in all cases to use this formula. I fancy not, as high current densities might necessitate such carbon brushes as would give commutation troubles.

I regret that for the want of time I have been unable to examine the formula for alternator regulation. I should be interested to know how these compare with the methods described by Hobart and with which the author is no doubt acquainted.

Mr. Cowan Mr. E. W. Cowan (of Manchester) said—This is essentially a paper for dynamo and motor designers, and therefore I am unable to criticise it or supplement any of the information which the author gives, but I should just like to say one word on the subject of regulation of generators. When I was associated with the construction of generators, I remember dealing with this question of regulation of alternators. It was at a time when there was a great difficulty in getting good regulation. Many of the alternators gave a drop of 50 per cent. between no load and full load. In the case of the machine I am now speaking of, we balanced the reaction of the armature by increasing the ampere turns of the field, and prevented a corresponding increase in magnetic induction by saturation in one part of the magnetic circuit.

In that way we were able to get a very fine regulation indeed—between six and seven per cent. between no load and full load with constant excitation. Mr. Cowan

Perhaps you will allow me to raise one other point upon which I should like to obtain from the author some information. Why is it that when the load is increased in an A.C. generator, the eddy current losses decrease? This phenomenon was observed by Dr. John Hopkinson and others, and in a model which we made for the purpose of verifying this fact, there was a very rapid decrease of eddy current loss when the load on the machine was increased. I have never been able to understand the physics of this, and possibly this may be an opportunity to learn something. We have all heard of that machine designed by Mr. Gordon, which took more power to drive it at no load than it did at full load, and perhaps this is due to the same cause.

Mr. JULIUS FRITH (of Manchester) said—I exceedingly regret that the author of the paper is not here, mostly because the few remarks I want to make will naturally take the form of criticism. Mr. Frith

If I appear to touch only on points on which I disagree with the author, I hope it will be understood that I do not do so through any lack of respect for the exceedingly useful work in the paper.

To take first a point of agreement, I think the author is right about designing motors for the higher voltage. In the lower voltage machines the smaller number of conductors and less space used for insulation will automatically make more room for the copper, without alteration of the size of the slots.

Then, as regards carbon brushes, I have always wondered why people prefer to speak of soft, medium and hard brushes. Why not say "low, medium and high resistance brushes."

I do not see the need for the diagram on page 329. No use seems to be made of it afterwards.

On page 330 I come to absolute disagreement with the author, where he says that it is the ampere turns per pole which limit the sparking. Now it is my experience that it is the ampere turns per inch diameter on the armature which limit the output through sparking, and I can show a whole line of generators with armature ampere turns per pole varying from 2,000 to over 10,000, all reaching their sparking limit at or near the same ampere turns per inch diameter.

Also in the "S" formula, I think the T should be squared, as the inductive voltage causing sparking certainly depends on the square of the number of turns per commutator bar.

Mr. Frith A previous speaker has referred to collecting from two spindles only on a wave wound multipolar instead of putting brushes on all the spindles. I do not think this makes the least difference to the sparking. The Westinghouse Company are only using two spindles on their four-pole motors where they might use the four sets of brushes.

I want to very much agree with the author in his remarks on the ratio of armature to field ampere turns per pole.

On a properly designed machine the armature can carry its full current with no field ampere turns at all without sparking.

I think it was W. Kapp who introduced a formula for the sparking limit in which he brought in the ratio of these two ampere turns per pole, and I think it did a great deal of harm.

Then, coming to the experiment on page 331, this I think is inconclusive. First, the machine was run at 500 volts and 820 revolutions. It was afterwards run at 500 revolutions, and, I conclude, at about 172 volts instead of 500 (taking the volts down in the ratio of the reduced speed and total flux). Well, you can naturally take more liberties with a 170 volt machine at 500 revolutions than with a 500 volt machine at 820.

Then, with respect to the table of tests given on page 333, I do not think much can be learned from it, because the machine seems to have behaved so exemplarily throughout. It is by what a machine will *not* do that knowledge is gained.

The paragraph on the top of page 334 seems to be paramount to saying that the tendency for a machine to spark is proportional to the voltage it is giving as the number of commutator parts is also constant for a given machine.

Page 335. Coefficient of friction ·3.—With the modern self-lubricating brush the coefficient of friction is not so much as ·3; probably about half this. This seriously alters the theoretical work on page 336. I think the density in brushes has to be settled apart from these theoretical grounds, as it so largely depends on *local* heating of the brush itself.

Now I come to the alternating current section of the paper, and, again, I find myself in absolute disagreement with the author, for I hold that the resultant demagnetising effect of the three phases is *twice* that of one phase. Like the author I, too, can predetermine the voltage drop of alternators with great nicety, but by using 2, *not* 1·5.

As to Mr. Eborall's diagram, by applying it to a two-phase instead of a three-phase armature, the resultant demagnetising force of the two-phase is shown to be the same as of the one-phase. Now we

know that if the load is put on to the other phase of a two-phase alternator you get a *further* drop. The demagnetising effect of a two-phase winding is, in fact, about 1·5 times that of one phase alone. Mr. Frith

The method on page 338 of getting the inductance of the armature is very ingenious, but I would point out that it is extremely difficult to get a watt meter to read accurately on these low power factors. With low voltage such as you have here, the indications of a watt meter may be very seriously out. Some of you will remember in this connection a curious paper read at the London Institution on "Loss in Cables."

Now, with regard to the demagnetising effect of the armature reaction of sychronous generators. Is it not a pity not to say at what point exactly you are considering this? I should prefer to take the point when the magnet pole is looking straight through the armature coil and then calculate the value of the armature current at that instant; this treatment clears up much of the difficulty evolved by considering demagnetising components and hypothetical internal voltages; the consideration of which latter has, I believe, led the author into a serious error, which I can best explain by reference to the calculations on page 345 for the total ampere turns required on the field magnets. The ampere turns to compensate for the demagnetising effect of the armature are stated correctly, but to these should be added the ampere turns required for the total volts, as read from the open circuit characteristic curve; but now comes our disagreement, for these total volts should be simply the terminal volts plus the *R.C.* loss in the stator, *not* the imaginary "internal volts," for there exists no flux in the machine to correspond to the "internal volts."

Mr. H. W. Wilson said—In rising to make a few remarks with regard to the paper, I regret I do not feel myself competent to answer the various queries that have been put forward, and I must, therefore, leave this for the author to do by correspondence. Mr. Wilson

I would, however, draw your attention to the notice at the top of the first page of the paper, which states "that the Society as a body is "not responsible for the statements made or opinions expressed in this "paper," and although I have had the honour of reading the paper I must take up the same attitude as the Society as a body.

I do not feel inclined to agree at once with all the author's statements. In the first place, he says, on page 328, that in his opinion it is better to design small machines for the highest voltage

Mr. Wilson required on account of simplicity, and in this opinion Mr. Frith agrees with him. I would, however, point out that Mr. Hobart in his paper on "Modern Commutating Dynamo Machines, with special reference to the Commutating Limit," read before the London Section of the I.E.E. in 1901, pointed out that "contrary to the ruling tendencies "there should in many features be greater differences between 500-"volt and the 100-volt machines for the same output and speed than "between two machines of the same voltage and very different "outputs."

Whilst I am quite prepared to admit the advantages as regards simplicity and standardisation of using identical dimensions of carcase all through for all voltages of small D.C. machines, it is not to my mind self-evident that the advantages more than counterbalance the drawbacks. This is, however, largely a matter of personal opinion, and one upon which it would be difficult to get all designers to agree.

On page 330, of course, the most important item is the formula for obtaining a limiting value for any given machine in order to ensure sparkless running. Most of the speakers have mentioned this formula δ, but they do not seem to have fully grasped what seems to be of essential importance, granted that it is applicable to all sizes of machines. Mr. Thomas says that he has checked out the value δ for various machines which he has under observation at present, but does not find that the results as regards sparkless running are such as the value of δ obtained for the different machines would lead him to expect. As regards this, I may say that it is very possible to my mind that the results may to a considerable extent be due to defective qualities of carbon brushes employed, as personally I have found most extraordinary differences in commutation obtained by changing brushes. Upon this point, however, I have one or two remarks to make later on.

In the formula δ for a machine with given output at a given speed requiring a fairly definite size of armature core, the only variables possible are ATp and T, and for large machines with one armature bar per commutator part we speedily come to a value of T equal to unity, the only variable is ATp, or, in other words, the formula for δ settles directly what the number of poles for a given machine should be, that is, of course, for a given style of armature winding, as otherwise the coefficient K has to be taken into account. Now Mr. Frith in his remarks states that he entirely disagrees with the author as to the importance of the numerical value of the quantity ATp, but states that

in his opinion the important quantity is the armature ampere turns per inch periphery of the armature. He agrees with the author, however, that it is of importance to use as strong armatures as possible. Mr. Wilson

Whilst I am prepared to admit that it is perfectly possible to obtain a formula, taking into account the armature ampere turns per inch periphery, giving a limiting value for sparkless commutation, I do not at all admit that this quantity can be satisfactorily embodied in the author's equation instead of the quantity ATp. In Mr. Mavor's paper on the design of continuous current dynamos he states that the quantity ATp should not exceed a value of 10,000 per centimetre length of air gap, and with this Mr. Esson agrees.

Mr. Hobart fixed the value for ATp very much higher than this, and whilst it is difficult to say what should be the limiting value, I am perfectly satisfied that the quantity is of importance in relation to commutation.

Mr. Frith also says that he considers that instead of using T in the formula for obtaining delta, the author should use T_2, but this I cannot at all follow. The author is not considering at all the question of reactance voltage, to which he evidently attaches very little importance, but states definitely in the paper that the tendency to sparking is directly proportional to the volts per commutator bar. Now the volts per commutator bar for a given armature are governed directly by the number of turns per commutator bar and not by the square of this quantity, and, therefore, I think that so far as this affects the formula the author is perfectly correct.

Before leaving the question of this formula, however, I should say that personally I should not be disposed to accept it without demur for all sizes of machines, and propose to see how it agrees with particulars which I have of some large units. The author appears, however, to have checked it carefully, and it may be quite correct for all sizes.

As regards page 331, however, and the experiments detailed thereon, Mr. Frith draws attention to a point which I had intended to raise, but in which he has anticipated me. As he points out, the experiment is of exceedingly little value owing to the fact that in the second experiment the speed was dropped and the flux density was dropped, and in consequence the voltage of the machine was reduced to the value of about 200 instead of 500, and therefore the voltage per commutator bar was very much reduced. Under such conditions one would naturally expect sparkless commutation, and although the

Mr. Wilson ratio between field ampere turns and armature ampere turns was very much reduced, still the reduction in voltage was certainly sufficient to more than counterbalance any tendency to sparking set up on this account, and therefore I agree with Mr. Frith in thinking that the experiment is distinctly inconclusive.

Mr. Cowan has raised the question as to why the iron losses of a machine diminish with increase of load, and upon this point I regret that I am unable to give any information, as it is a question that I have never heard satisfactorily explained. It occurred to me, however, as being possible that as the armature reaction opposes the main flux, the flux density is reduced in some portions of the magnetic circuit, and that, consequently, the hysteresis loss in ergs per cycle is reduced in some portions of the machine. I am only hazarding this as a guess, as it is a subject that would require most careful investigation before any satisfactory explanation could be arrived at. I do not see at all how it is possible for the eddy current losses to diminish with increase in load.

Before closing my remarks, as I do not feel competent to reply to the points raised in connection with the A.C. machines I should like to say a few more words about carbon brushes.

My somewhat painful experience on this subject has led me to the conclusion that when a machine is designed the designer states the size of carbon brushes that he wishes to have used, and that for the first batch of machines the quality of brush he specifies may be used, but after that the purchasing of brushes is left entirely to some clerk, who goes for lowest price, and consequently you get brushes with a resistance totally unsuitable for the voltage they are working on, and therefore you get sparking. Of course I do not say that this is the case with all firms, but I have seen so many instances where sparking has been due absolutely and entirely to carbon brushes that I am satisfied that insufficient attention is given to this point. If it is customary to use brushes of the same size but different qualities, it is so difficult to impress upon workmen and store keepers that different voltages require different qualities of brush.

As I said before, I do not intend to make any remarks about the second part of the paper, but wish to add my thanks to the other speakers in expressing my obligation to the author for the very interesting and suggestive paper he has written for us.

Mr. Kirkpatrick Mr. W. D. Kirkpatrick said—Dealing with the "continuous current part" of the author's valuable paper and formula given for the determination of. My experience has been that it is quite possible to

convert a machine with a decided tendency to spark into a reliable running and sparkless machine, given, of course, that the commutator is perfectly smooth and in good running order. Mr. Kirkpatrick

In one or two small machines recently, the question of sparkless running, or otherwise, was not considered in the design at all and a certain quality of carbon brush used which produces this effect perfectly, although the brushes are incapable of being rocked at all.

The question, at all events in small machines, appears to turn solely upon the hardness, or rather resistance, of the brush used.

Turning now to the question of friction losses on commutators, the difficulty experienced appears chiefly to be that of obtaining a suitable material to maintain a constant pressure on the brush, both when it is newly inserted and also when it is getting pretty well worn. From experiment the point where machines are most efficient from a frictional view appears to be an unstable one with regard to the weight bearing upon the brush. There is a further difficulty of once having secured a suitable spring, of preventing the users of the machinery from altering it and thereby defeating the object of its use, viz., to produce contact between brush and commutator without undue friction. Unfortunately the question of design of brush holders is not touched upon in the paper, but as this is after all a very essential part, especially in small machines, it will be interesting to hear the author's opinion on this matter.

In conclusion, I should like to ask if the author has any experience with a form of winding especially brought forward as being a good one by certain American text books, which consists of paralleling the armature, that is to say, in a Bi-polar machine having two separate and complete circuits in the armature. This question, of course, applies to motors, not dynamos.

Mr. W. B. Esson said—In Part I the author refers to the designs of continuous current dynamos for 200 and 500 volts respectively and suggests that machines up to 100 H.P. should be designed for the higher pressure, thus making sure that they will be right for the lower. This is, of course, very safe practice, and I quite sympathise with the object the author has in view; at the same time some designers would say that the lower voltage machines were then unnecessarily expensive, and in these hard times, when machines are almost being given away, too much generosity in material does not do. But that the course the author proposes simplifies shop work and keeps down the stock of parts is undoubted, and that is no small matter. Mr. Esson

Mr. Esson One feels that one should know a great deal about commutation considering all that has been written about it, but it is really surprising how very inexact one's knowledge is. We know the factors that enter into the problem, but of the exact influence to be attached to each of them we are, I am afraid, very ignorant. Most of the papers on the subject merely reiterate in a new form the rule which guided us in construction twenty years ago, viz., to see that the interference of the armature field with the main field was not too great, and to divide up the armature winding among as many commutator segments as possible. I do not say that we do not know more now than we did then, but simply that our modern knowledge has but served to show that our ancient practice was right.

Referring to the author's expression for the tendency of a machine to spark, this illustrates very well the remarks made above. It is a purely empirical expression, and I have not the least doubt that it has been of great service to the author. In the present state of our knowledge it is unavoidable that empiricism enter into our formulæ, and it is most interesting to find as knowledge advances that empirical expressions have often had a thoroughly scientific basis, but I must confess I am not much taken with this expression of the author. To me it appears to be behind the knowledge we have acquired, and its application must be very limited. In effect the expression says that taking a machine of certain linear dimensions you may half the number of commutator segments and double the number of poles without making any difference in the tendency to spark. Now that certainly is not right as a general statement. If the limiting figure for δ is chosen so as to include the greatest value T is ever likely to have, perhaps the expression might be useful, but it would require recasting altogether to become general.

The sparking propensities depend greatly on the reaction voltage and this is proportional to AT^2L, where A is the amperes per armature path, T the number of turns per commutator segment and L the length of the armature core. This is evident from the fact that the field produced by the current is proportional to ATL, and this, induced through T turns, gives AT^2L for the reaction voltage. In saying that the reaction voltage is proportional to this product it is implied that several things come in to determine its value, and amongst these is the degree to which the armature induction is carried. Obviously the reactage voltage is proportional to the *change* of field produced by the short circuiting of the coil, and the less this is the less is the tendency to spark.

Mr. Esson

But while we can affirm with confidence that the sparking is influenced largely by the reactance voltage, we cannot calculate with any degree of certainty the exact value of the latter. It has been assumed that the current during the short circuiting of a coil gradually dies down to zero and rises again to maximum in a sinuous curve before the short circuit is removed, and, though this enables an approximate value to be set upon the reactance volts, the assumption rests on no real foundation. The frequency of the current to which the reactance is due depends upon the speed, the total number of segments in the commutator and the number covered by the brushes at one time, but to get a gradual fall and rise of current obviously the short circuited section must be moving in a magnetic field, in other words, there must be a considerable fringe of lines in the vicinity of the pole. This brings me to another thing that comes in if fixity of brush position is required, and that is the number of ampere bars per pole, for upon this depends the distortion, or, in other words, the moving away of the fringe from the brushes when it is most needed, and consequently the possible necessity for shifting the brushes. The less the reactance volts the less the fringe required, and the less the ampere bars the less movement is there of that fringe. Some designers say that if the reaction is low enough all considerations respecting the fringe field may be put aside, at the same time I think the author would be perfectly right in introducing into his formula some term taking account of the ampere bars, seeing his expression is intended to set a limit on the sparking tendency for fixed brush position. But, as I say, the expression will want recasting if it is to be taken generally, and some coefficient will have to be introduced which takes due note of these various factors.

The question of sparking depends to a considerable extent, as the author of the paper truly says, on the kind of brushes employed, and again it very largely depends upon the output coefficient of the machine. From the figures given I am unable to judge as to whether the machines cited are large for their work or otherwise, as the data are incomplete. The most successful designer is, of course, the one who can get the greatest output at least cost, and under the condition that the machine shall not develop any vicious tendencies.

Touching on alternating current machines, I think the author is incorrect in assuming that the effect of superposed phases on the magnetic fields can be treated by Vector diagrams. The Vector resultant of two currents in quadradnature, each having a value of unity is 1, but the resulting field, if the coils carrying these currents

Mr. Esson are wound side by side on a piece of iron is quite different, and this is what we have in actual machines. The iron has the effect, so to speak, of defecting the Vector paths and while, as a contribution to general theory, Vector studies are both interesting and instructive, wherever you have constraint such as produced by iron cores, the Vector treatment no longer applies.

The polyphase motor of which particulars are given appears to be of normal design, but I have grave doubts as to the figures given for the power factor. In ten years' experience of induction motors I have never known a 20 H.P. machine give anything like 93 per cent. power factor, and judging from the design 85 or 86 per cent. for the author's machine would be much nearer the mark. Perhaps the author has only calculated the power factor which would account for the difference. If he has measured it, some terrible mistake must have been made in the measurement.

Mr. Mavor Mr. H. A. Mavor said—I am afraid I cannot agree that the author's formula for denoting the tendency of a machine to spark is by any means universally applicable. He leaves out of consideration the field density and the length of the air gap.

The formula given embodies the other elements necessary to determine the sparking qualities of the machine, and probably for a group of machines of similar design would fairly represent their qualities with the exception of value K. I do not understand why an armature of given dimensions should give a different total output depending on whether it is lap or wave wound. The experiments described on pages 330-332 are subversive of one's notions of the matter in question. Would the author please embody in his reply particulars of the length of air gap, the area of poles and the magnetising current of the machine?

A full specification of this machine would be interesting, further particulars required being depth, width and number of poles. Perhaps the author would be good enough to supply these particulars in his reply to the Discussion.

Mr. Hobart Mr. H. M. Hobart said—I was very much pleased to find in the author's paper so much evidence of having largely discarded time-honoured conventions. The reverence for traditional ratios of gap ampere turns to armature ampere turns and for other absolutely useless constants, has for years seriously impeded progress in continuous-current design. I would suggest that the subject of induction motor design is also beginning to suffer in a similar manner. Fortunately, however, it had arrived at a higher state of development before practice

began to crystallize into tradition. A point in which I take a rather keen interest has reference to the advantages, as relating to low first cost, high power factor and high efficiency, which accompany the use of squirrel cage induction motors. The futility of employing short air gaps, unless the number of slots per pole is great, is another point which I believe has not been realized, owing to an insufficient appreciation of the elements affecting the "zig-zag" dispersion over the heads of the teeth. I have found that this "zig-zag" dispersion is a function of the product of radial depth of air gap and number of slots per pole. Mr. Hobart

The effect of the inductance of the end connections is still greatly underestimated, not only in the design of continuous current machinery, but still more in the design of induction motors, and to the greatest extent of all, in the design of alternating current generators. This often leads to employing too large diameters, as does also the erroneous theory that a high peripheral speed necessarily contributes to an economical design. Modern ventilation permits of a high loading of the armature as expressed in ampere conductors per unit of periphery, both in continuous current and alternating current design, and hence to increased output for a given expenditure.

The author's commutation formula is a disguised form of the customary reactance voltage method. It fails, however, to take into account the inductance of the end connections. It should also be mentioned that the value of K would be different for every different number of poles. His remarks, as they stand, appear to be correct only for four-pole machines. To give an instance of the danger of trusting to his commutation formula, I will apply it to the 1600 K.W. the 22-pole generator, described on pages 695-697 of Vol. of 7th edition (1904) of Dr. Thompson's "Dynamo Electric Machinery." For this machine—

$$ATp = 7900$$
$$T = 1$$
$$L = 13$$
$$R = 85$$
$$K = 1$$

Hence $= 7900 \times 1 \times 13 \times 85 \times 1$

$= 8{,}700{,}000$

$= 8 \times 10^6$

The author of the paper states that 50×10^6 ensures perfect commutation. This would, however, correspond to a reactance voltage of 23 volts. The 16-pole 1000 K.W. machine, described on pages 632 to

Mr. Hobart 644 of Dr. Thompson's work would, if it could be worked up to 50 = $\times 10^6$ have a reactance voltage of 17·5 volts. Hence, when we read that "the author has found the formula to hold good for machines of all "sizes," we must assume that he refers to 4-pole machines. He would get into trouble if he should trust to his formula in designing larger machines. If the values of the reactance voltage derived for the 22-pole and 16-pole machines are reduced in the ratio of $\frac{4}{22}$ and $\frac{4}{16}$ respectively, we obtain 4·2 volts and 4·4 volts respectively, which are reasonable values for machines of their proportions and speeds. It is, however, much safer to employ formulæ which take into account the inductance of the end connections. Two expressions, both of which allow for the inductance of the end connections, are as follows:

Formula I.—Reactance voltage $= \dfrac{\pi\, A\, q\, r\, (1{\cdot}2\, \tau + 8{\cdot}0\, \lambda\, n)}{b \times 10^5}$

in which A = peripheral speed in meters per second.

q = number of turns per segment.

r = number of simultaneously short circuited conductors per group.

τ = polar pitch at air gap in centimeters.

$\lambda\, n$ = nett length of armature laminations in centimeters.

b = length of arc of brush contact in millimeters.

Formula II.—Reactance voltage $= \dfrac{8\, \pi\, q\, 0\, (\lambda n + 0{\cdot}15\tau)}{P\, M}$

in which q, λn, and τ have the same significance as in Formula I, and

O = Output of armature in watts.

P = No. of poles.

M = Flux in *c.g.s.* lines entering armature per pole.

The data given with regard to the properties of different grades of the Le Carbone Co.'s brushes, is of much interest. Further investigations on these lines are greatly needed. Tests such as that of which the results are given in the table on page 333, but made successively with

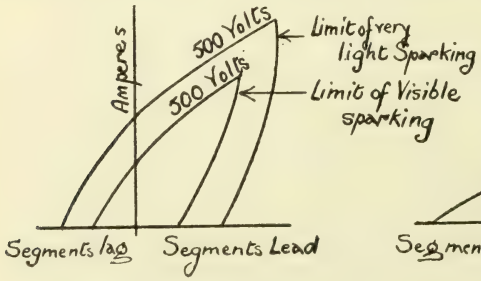


FIG. 1.

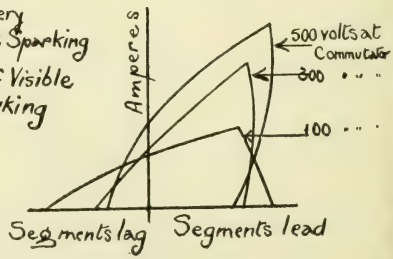


FIG. 2.

widely different grades of Le Carbone brushes, would permit of plotting some very interesting curves of the sparking limits for different grades of brush. The curves should preferably be plotted in some such way as I have described on page 451 of Vol. L (14th March, 1902) of the "Electrical Review," in an article entitled "Armature Interference and Brush Position." These curves are reproduced in Figs. 1 and 2, page 362. Mr. Hobart

Mr. J. Fierz said—Referring to Part I.—Continuous Current Machines.—In looking at the expression for δ, the figure denoting the tendency to spark, I find that it should contain the number of poles. Mr. Fierz

It is indeed easy to show that the expression as it stands cannot be correct. A six-pole machine, lap-wound, having the same elements per pole as a four-pole machine and running at two-thirds of the speed of the latter, must evidently have the same commutating qualities. ATp, TL and K are the same in both cases, and it follows, from the author's formula, that δ for the six-pole machine would only be two-thirds of the value for the four-pole machine.

If, however, another factor proportional to the number of poles is added, the value for δ in the two cases becomes the same, as it ought to do.

Very likely the author used his formula for four-pole dynamos only, and so this escaped him.

With the above correction we recognise immediately that apart from certain constants, δ is nothing else but the reactance voltage as defined by Hobart (See "Journal of the Institution of Electrical Engineers," No. 153, Vol. 31). The author of the paper assumes that the self-induction of an armature coil only depends upon the length of the core. This is, of course, not correct, but is near enough for comparing machines of similar proportions, both with regard to pole pitch and length of core, and also with regard to the shape of the slots.

For the armature, the dimensions of which are given in the paper, the reactance voltage for 820 R.P.M. works out to 3·2 volts by Hobart's formula.

Hobart gives about three volts as the limit, which agrees with the experience of the author. These formulæ are very useful indeed, but it must always be borne in mind that they are only approximations.

It would be a great mistake to conclude that for machines with a high reactance voltage it is impossible to obtain sparkless commutation without moving the brushes.

In this case, however, a suitable commutating field has to be provided either by means of specially shaped pole type or by using a

Mr. Fierz compensating winding. For high speed dynamos it is impossible to keep reaction voltage within the limits indicated.

It is difficult in this case to determine the commutating qualities; Professor Dr. Arnold, of Carlsruhe, has dealt fully with the general problem of commutation in his book, "Die Gleichstrom Maschine."

Part II.—Alternating Current Machines.—I do not see why the author makes use of the analytical method when the same subject has been treated by several writers by means of diagrams in a considerably simpler way.

Proceeding graphically we find the different values in the following diagram :—

Making $Cos.\ \phi$ = Power Factor

$O\,A$ = $P\,D$ (Terminal pressure)

$A\,B$ = $C \times Rg$

$B\,D$ = $p \times Lg \times C$

we find in $O\,D$ the internal E.M.F.

Is

$O\,F$ = Nett ampere turns.

(taken from the no-load characteristic)

$F\,G$ = Armature ampere turns.

so $F\,H$ is what the author calls the demagnetizing ampere turns.

This is easily shown from the equation on page 340.

$$C_2 = \frac{p \quad L \quad C}{\sqrt{R^2 + p^2 \quad L^2}}$$

it follows :—

$$\frac{C_2}{C} = \frac{p \times L \times C}{\sqrt{R^2 \times C^2 + p^2 \times L^2}} = \frac{p \times L \times C}{C^2 \quad E} = sin\ \psi$$

or demagnetizing ampere turns = Armature ampere turns $\times\ sin\ \psi = F.H.$

According to the author :—

Gross ampere turns = nett ampere turns + demagnetizing ampere turns

$$= O\,F + F\,H = O\,H.$$

This does not agree with my experience. Most designers take $O\,G$ for the gross ampere turns, and I find this to be very near the truth. As a rule it will still give too small a value, as the increase of the leakage in the inductor, from no load to full load, is not taken into account.

It is easy to see that for a purely inductive load the two methods give the same result, G and H falling together, while for power factors approaching unity, there is an appreciable difference.

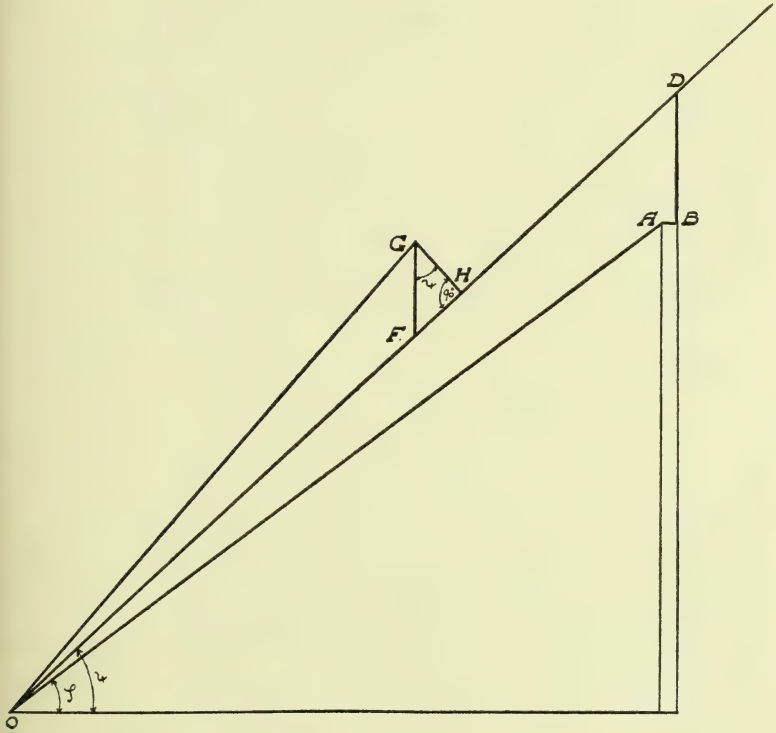
The author gives in his example :—

Armature ampere turns = $1{\cdot}414 \times C \times 6$ (6 being number of turns per coil). This evidently refers to a two-phase and not to a single-phase alternator.

Mr. Fierz

The reactance voltage of the armature is given as 320 volts for full load current, *i.e.*, 16 per cent. of the normal terminal pressure. This is a much higher value than would be found in a standard machine; perhaps the author refers to an alternator with closed slots, in which case this may be possible.

With regard to the three-phase induction motor, although I have only gone very roughly into the matter, I should like to express my doubts as to the very high power factors quoted.



Mr. Meyer

Mr. H. S. Meyer said—Designing papers such as the one under discussion, are difficult to criticize in their details, as the work involved in checking the usefulness of the different formulae brought forth, would be excessive. Therefore, one has to limit oneself to a few points of a more general character.

In regard to the question of designing direct current machines for high or low voltage, I think the author cannot deal with this point without giving consideration to the question of speed and output.

Mr. Meyer I always found that large machines of high speed are better for higher voltage, while small machines for slow speed are better for lower voltage.

Next, the point of sparkless commutation. Here I do not quite agree with the arguments of the author. From page 334 I note that his formula for sparkless commutation culminates in the sentence, that the tendency to sparking will be proportional to the volts per commutator bar. Now it is a well known fact that the volts per bar have very little influence on commutation, which depends almost entirely on the ratio of $\frac{\text{resistance of commutation}}{\text{reactance of short circuited coil}} = \frac{r}{x}$ where r includes the resistance of the short circuited coil, and the contact resistance of the brush; if the latter is very high, as apparently in the type the author refers to, commutation will become almost entirely a resistance commutation, such as for instance, used in railway motors. This would also explain the good results obtained with the very weak field referred to on page 333. However, to rely on resistance commutation only is inefficient, and therefore to ensure sparkless commutation, the reactance voltage as expressed by $2\,\pi\,n\,LI$ should not exceed 2 to 3 volts at any load. Here n = frequency of commutation =

$$\frac{\text{peripheral speed of commutator}}{\text{twice thickness of brush}}$$

L = coefficient of self induction.

I = current in one armature circuit.

In addition to the reactance voltage, the proper distribution of the flux under various loads has to be considered, and therefore the shape of the pole enters with considerable importance into the question of sparkless commutation. This is the generally accepted theory, and any formula which does not cover these points must be more or less limited in its usefulness.

Commutator Losses.—Here the author states, for the particular quality of brush used, that the gain in reduction of contact resistance by increased pressure of the springs, will be a good deal more than the increased loss due to friction. This statement should be taken with great caution when dealing with other brushes. Generally, it would not be advisable to go with the pressure beyond a certain limit, say, 2—2½ pounds per square inch, as otherwise the wear of the commutator will be excessive, and also the well known law of equality between commutator friction and C^2R would be seriously upset; further, the question of noise in operation may become serious.

Mr. Meyer

In regard to Part II, dealing with alternating current machines. The author refers here to the value of armature reaction in three-phase generators. He mentions that a difference of opinion exists among designers whether the resultant ampere turns are equal to 1·5 or twice the maximum ampere turns per phase. In my opinion, there cannot be any doubt that for true sine waves, the resultant magnetizing force of a three-phase winding is theoretically equal to 1·5 times the maximum magnetization of one phase. The difference of opinion only begins in practical cases and when the self induction of the armature winding, which cannot readily be separated from the above magnetization, is to be covered by the expression "armature reaction." Then a figure from 2 to 2·5 times the maximum ampere turns per phase—according to the design of the machine—will mostly represent the correct value of the resultant armature strength.

Further, as to the analytic method used by the author for predetermining the regulation of alternators, I think the well known graphical representation, as also referred to in my paper on "Voltage Regulation in Alternating Current Systems" read before this Society, using the triangle of ampere turns, is preferable both from the point of simplicity and accuracy.

Finally, the author deals with polyphase induction motors. It would have been interesting if some further data such as length of air gap, size of slot and dimensions of wire had been given, so as to enable an independent checking of the data given by other methods.

While I differ from the author in the various points referred to above, I consider his paper a very interesting contribution to the subject on the design of electrical machinery.

Mr. Hunt

Mr. Louis J. Hunt, in reply, said—The paper, as the President was good enough to point out, was written under circumstances which did not permit of the proofs being properly corrected, and I feel that an apology is due to the members for the many errors which crept in. As a considerable part of the discussion deals with the continuous current portion of the paper and particularly with the commutating formula, I would at once like to correct the error which has been pointed out by several gentlemen in the expression as printed. As given, the formula is correct only for four-pole machines and requires multiplying by $\frac{P}{4}$ to make it generally applicable. It originally included the frequency of the machine instead of the speed in revolutions per minute, and it was in changing the units that the error occurred.

Mr. Hunt With regard to Mr. Eustace Thomas' remarks on this formula, it is not correct to take the peripheral speed of the armature into account, as the frequency is used instead. $\frac{P}{2}$ is to be used when the armature is wave wound and two sets of brushes only are used. The fundamental idea is that the E.M.F. producing sparking at the brushes is due to the armature flux, the periodicity of the machine, and the number of turns between two commutator segments; it will therefore be clear that the number of commutator segments covered by the brushes has nothing to do with the E.M.F. thus generated. Mr. Thomas suggests that the size of slot should be taken into account, but I have found this to be quite unnecessary, and when one considers that the number of slots per pole is always large, and also that the pole faces also form a path for the armature flux, I think it will be obvious that the form of slot will not make much difference to the leakage flux. Saturation of the pole tips and splitting the poles themselves may permit of a larger value of δ being permissible, and experiments upon machines with split poles would be of great interest. I quite agree with Mr. Wilson that unsuitable brushes would quite account for the variations in the commutation qualities of the machines mentioned by Mr. Thomas. The formula for commutator losses takes into account both peripheral speed and contact density, and I therefore fail to understand the points raised by Mr. Thomas, unless he refers to the effect of peripheral speed upon the contact resistance of carbon brushes. Numerous experiments show this to be negligible. Of course it is not intended to use the formula as a hard and fast rule, but it will indicate the area of contact which will give the smallest losses.

The same speaker also asks how the method of predetermining voltage regulation in alternators compares with that given by Messrs. Parshall & Hobart in "Engineering" a few years ago. When these articles appeared I worked out the examples given by the method described in the present paper and found in each case a far clearer agreement with the test results than was obtained by their method.

Mr. Cowan raised a very interesting point as to the decrease of the eddy current losses in an alternator with increase of load, but I regret that I cannot supply a satisfactory answer.

Mr. Frith has, I think, misunderstood the commutator formula. The armature ampere turns, considered by themselves will, of course, form no criterion as to whether a machine will spark or not. What the formula does show is that if an armature be provided with a winding having (say) two turns per commutator part, it will reach its sparking

limit when carrying one-half the number of ampere turns it would stand with a winding having one turn per segment, and this is obviously true. It is therefore quite misleading to consider only the ampere turns per inch of diameter. If Mr. Frith refers to machines designed for (say) 550 volts, the commutators having the maximum number of segments mechanically permissible, then the number of ampere turns may form some guide. Referring to the expression at the foot of page 332 we have— Mr. Hunt

$$\delta = \frac{75 \times w^7 \times A\,Tp \times L \times E \times P}{F \times Y}$$

If a minimum thickness of commutator segment be taken we may write $Y = K'D$ where K is a constant. For machines of similar design we may write $F = K''DL$. Where D in each case is the diameter, and L the length of the core. This assumes that the flux density in the gap will be above constant and that the ratio of diameter of the commutator to that of armature is fixed.

Substituting these values in the above expression.—

$$\delta = \frac{75 \times 10^7 \times AT \times D \times L \times E}{K'' \times D \times L \times K' \times D}$$

Where AT' = total ampere turns of armature

$$\text{Let } K = \frac{75 \times 10^7}{K' \times K''}$$

$$\therefore \delta = \frac{K \times AT \times E}{D} = KE\,AT'$$

AT' = ampere turns per inch diameter.

T must not be squared in the expression as the strength of the flux has to be taken into account in ATp and the induced E.M.F. is a function of $T \times ATp$ and not of T^2.

The experiments described on page 331 were only made to show that with a sufficiently low value of δ, the ratio between (gap and tooth) ampere turns to armature ampere turns will have no effect upon commutation. As to the coefficient of friction of carbon brushes I have found by experiment that ·3 is correct for the make of brush mentioned in the paper. With regard to Mr. Frith's remarks on the alternating current section of the paper, I quite agree with him that currents in the two phases mutually affect one another but that does not affect the question of the resultant ampere turns, for each phase provides half the resultant ampere turns, and in the same way each phase of a three-phase machine supplies one-third of the resultant ampere turns. It can be shown analytically that if the currents in the different phases be balanced, the resultant of half the ampere turns of the two or three phases will cancel one another out.

Mr. Hunt In reply to the same speaker with reference to method of predetermining voltage regulation, C_2 represents the value of the current when the magnet pole is looking straight through the armature coil. I certainly cannot agree with Mr. Frith that the total volts generated by an alternator equals the terminal voltage plus the CR drop in the winding. This is very nearly true for a machine running on a non-inductive load but does not hold when the load is inductive, owing to the drop in pressure due to the inductance of the windings.

With reference to Mr. Wilson's remarks, I certainly think that it is preferable to use the same size carcases for machines of any voltage up to (say) 600 volts and to correct for the differences in the commutating qualities by using suitable grades of brushes. By this means the commutator losses may be made more equitable, and the efficiency of the higher voltage machines will be higher than would be obtained by using longer and weaker armatures.

In reply to Mr. Kirkpatrick, my experience with parallel or duplex, triplex, &c., windings, has been that for old fashioned two-pole machines they were perfectly satisfactory, but that for multipolar machines they are very much the opposite. I believe most firms have given up their use.

With regard to Mr. Esson's remarks, the unfortunate error in the commutative formula explains the anomaly he points out, but I should like to explain that the expression can hardly be called empirical as δ really represents an actual E.M.F., the expression in its more scientific form being :—

$$\delta = 4.4 \sim . F_A \; TK \, 10^{-8}$$

The dimensions of the 75 K.W. dynamo required by Mr. Esson are as follows :—Diameter of armature 21 inches, length of pole face 11 inches.

As to the value of the power factor of the 20 B.H.P. induction motor, the figures were calculated ones but have been confirmed on test, when the maximum value was found to be 93·6 per cent., the commercial efficiency for the same load (21·5 B.H.P.) being 88·5 per cent. The instruments used for the test were Addenbrooke electrostatic ones, and were calibrated immediately before and immediately after the readings were taken, so that no error can have occurred. Perhaps Mr. Esson has overlooked the fact that the machine is a 25 cycle one.

In reply to Mr. Mavor, I may say that I have worked out a very large number of machines of different design, and can affirm that the sparking formula holds good for any type and any size of machine.

As bearing on this point I append a list of a few machines taken from various sources, giving in each case the value for δ. Mr. Hunt

Size of Machine.	Designer.	$\delta \times 10^{-6}$	Reference.
·5 B.H.P.	Mr. Williamson ...	44·5	"Electric Motors" in "Traction and Transmission"
5 "	" " ...	32·6	" "
25 "	"Castle" Motor ...	41·5	" "
10 "	Union Company ...	60·0	" "
5 "	Mr. Mavor ...	53·8	" "
30 "	" " ...	21·2	" "
20 "	Mr. Clayton ...	58·0	" "
35 "	" " ...	29·0	" "
·00 "	" " ...	44·6	" "
·00 K.W.	— ...	91·8	"Electric Generators" Messrs. Parshall and Hobart.
·00 "	— ...	51·6	" "
·00 "	— ...	38·2	" "
·50 "	— ...	45·0	" "
50 "	Scott & Mountain ...	30·8	"Dynamo Electric Machinery" 7th Edition
·40 "	The Walker Co. ...	29·3	" "
·80 "	Brown, Boveri & Co. ...	60·5	" "
·00 "	Mr. Hobart ...	44·6	" "
·00 "	The Oerlikon Co. ...	71·2	" "
·50 "	The General Electric Co.	41·6	" "
·00 "	The English Electric Co.	52·0	" "

Mr. Mavor considers that the expression for sparking should take into account the length of air gap and field density, but I have found that if machines be designed to work with a value of δ not exceeding 50×10^6 they will commutate satisfactorily with any strength of field. The particulars asked for by Mr. Mavor are as follows :—

Length of air gap	=	5 milimetres.
Area of poles	=	841 sq. centimetres.
Shunt turns per pole	=	1600.
Number of poles	=	4.

With regard to Mr. Hobart's remarks, I quite agree with him that as a general rule a strong armature means a cheap machine, but it does not do to make small armatures too strong, as beyond a certain

Mr. Hunt limit the output of small machines will fall off owing to the decreased space factor due to increasing the number of armature turns. By reducing the depth of the slots of some small 10 to 30 H.P. machines by $\frac{1}{8}$ inch, recently, it was found possible to increase the output when wound for 500 volts by 15 per cent. and to improve very greatly the commutating factors. The previous remarks as to the error in the commutating formula explain Mr. Hobart's reference to the 1600 K.W. dynamo for which the value of δ should be 48×10^6. Mr. Hobart states that the commutating formula is a disguised form of the reactance voltage method, but if this be so the disguise must be a very thorough one, as will be seen by working out the values of the reactance voltage and δ for any machine. The method of calculating the R.V. given in Messrs. Parshall & Hobart's "Electric Generators" does not allow for the inductance of the end connections. Reference to the machines described therein will therefore be fairer than to later machines in which the inductance of the free length of the windings has been allowed for. Obviously if the two methods be the same, the ratio between R.V. and δ should be, roughly, constant, and the following table giving both values for the machines described in "Electric Generators" shows that this is very far from being the case.

Size of Machine.	$\delta \times 10^{-6}$	R. V.	$\frac{\delta \times 10^{-6}}{\text{R. V.}}$
1500 K.W.	91·8	8·0	11·45
200 "	51·6	7·85	6·58
300 "	38·2	4·4	8·68
250 "	45·0	4·7	9·58

In calculating the reactance voltage by Mr. Hobart's method, the flux considered is due to the ampere turns of the simultaneously short circuited coils situate in a small number of slots, often not more than one or two. These conductors are in the position of minimum inductance, and it is therefore clear that the inductance of the end connections will form no inconsiderable portion of the total inductance of the short circuited coils. In the method described in this paper the flux is that of one pole of the armature and this flux is not confined to a small number of slots, but must be calculated on the basis of the total number of armature slots per pole. The magnet pole faces also form part of the path of this leakage flux and increase its value far above that due to leakage across the slots alone. Owing

to the long length of the path through air the leakage flux due to the current flowing in the end connections spanning a whole pole pitch will be small and its relation value will be still further reduced when we consider that the slots are not in the position of minimum inductance. For these reasons I hold that the strength of the armature field will not be much increased by the end connections, and, that neglecting them will not materially affect the accuracy of the method. Mr. Hunt

In Mr. Hobart's paper on "Modern Commutating Machinery" (see "Journal Institution of Electrical Engineers," No. 153, Vol. 31) 3 volts is given as a safe value for the reactance voltage, but it is pointed out that for large slow speed machines the permissible limit increases considerably with the size of unit. This variation does not appear in the δ method, as will be seen from the following table.

Size	$\delta \times 10^{-6}$	R. V.	Reference.
200 K.W.	51·6	7·85	"Electric Generator."
250 K,W.	45·0	4·7	do. do.
400 H.P.	44·6	3·1	"Electric Motors" in "Traction and Transmission."
10 H.P.	60·0	2·8	do. do.
5 H.P.	53·8	2·58	do. do.

With reference to Mr. Fierz' very interesting remarks, the alternator given as an example was a hypothetical one, used only for purposes of illustration. I have found that the analytical method described gives far more accurate results than can be obtained by means of any graphic method with which I am acquainted. I have plotted curves for machines working on loads having different values of power factor and have found them agree very closely indeed throughout the entire ranges with the test results. The inductance of the windings has been taken at the same value throughout.

In reply to Mr. Meyer, I think he has misunderstood the expression maximum voltage per commutator part. Of course used generally the voltage per segment is no guide at all to the commutating qualities of a machine, but what the formula does show is that for a given machine having a definite strength of field and number of armature ampere turns, the sparking voltage is proportional to the volts per segment.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

TWELFTH MEETING—6TH APRIL, 1904.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

PRESIDENT, IN THE CHAIR.

SOME EXPERIMENTS WITH VARIABLE PITCH PROPELLER BLADES.

BY A. H. CRUMP, M.I.M.E.

THE author's attention was drawn, some little time ago, to the behaviour of a built propeller, whose blades, of uniform true screw design, were capable of being slewed round to a pitch $2\frac{1}{2}$ feet "more or less" in excess of that to which the blades were originally moulded. This was rendered possible by the usual device of slotting the stud-holes in the palms of the blades in the required direction, to the extent above mentioned. In the course of our manipulation of the diagrams you see before you the exact measurements of such slotted holes will be correctly ascertained.

You will observe that the author says $2\frac{1}{2}$ feet *more or less*; for when he came to decide upon a proposed variation of the pitch of these blades, he also had to decide which position on the blade should be the one chosen for measurement of pitch, because it struck him, as it must strike you, that when once a blade is twisted from its normal position, its varying angles no longer correspond to those of a true screw; and although its pitch might be 17 feet at one position on the blade, it would be 17 feet plus or minus some variation on any other position.

So the author came to the conclusion that he had better work the whole matter out on the drawing board; and having done so with much care and repeated checking, the results, reduced to diagram form, seemed to him so full of interest, that after a word or two on the subject with a couple of friends in the Engineering profession in Liverpool, he decided to offer the investigation to your President, in the hope that it might engage the attention of members of the Society, and give rise to a discussion from which he hopes to learn something further on the subject.

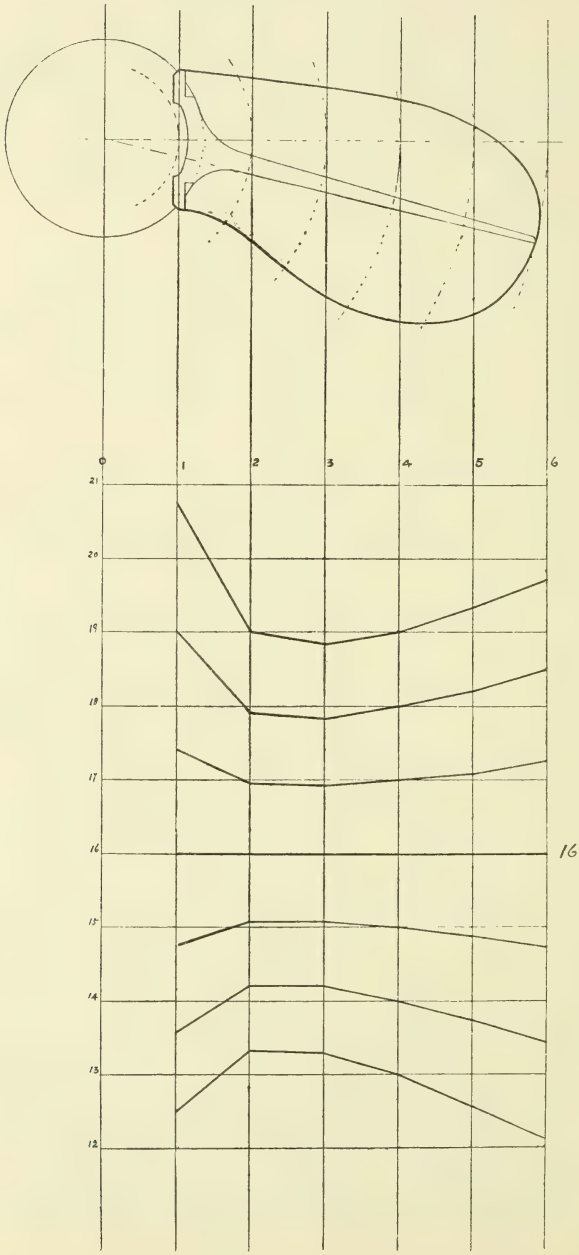
For the purposes of this communication the author has here before you a sketch of the development, on the flat, of such a blade as he described in his opening sentences, together with pitch diagrams in duplicate, one on drawing paper and the other on tracing cloth, and in addition, a Table and diagram showing the results of the enquiry in graphic form, which will be useful for reference as he proceeds with his description of the modus operandi.

The propeller which the author has sketched is shown by its pitch diagram to be a true screw of 16 feet pitch and 12 feet diameter; and, without getting out the details of the slotted stud holes in the palms, he has assumed that it is capable of a variation in pitch on the 4 feet radius of 3 feet above and below its true pitch; viz.—from 13 feet to 19 feet in all. He is aware that it is not usual to slot the holes so as to admit of reduction of pitch, as it is assumed that what will be required will be more probably an increase, but there can be no harm in seeking to know exactly what will happen in both cases. Moreover, he has carried his enquiries in both cases far beyond any reasonable practical limits, for he holds that one of the best ways to prove the desirability or otherwise of a departure from accepted true form is to carry such departure to extremes and thereby establish, as in this case, a "reductio ad absurdum."

The author will now conduct you through the very simple stages of the experiment, using for apparatus the drawing and tracing before mentioned.

By applying the tracing over the drawing and selecting as a pivot the point on the thwartship or path line of the blade, which corresponds to the circumference of a circle with a 4 feet radius, we can deflect the line on the tracing which shows the angle of the blade at this radius until it cuts the fore and aft or pitch line on the drawing at any desired point.

The author has drawn his diagrams to a fairly large scale, $1\frac{1}{2}$ inch to the foot, in order to render them conspicuous, and the pitch line is


0
1
2
3
4
5
6
21
20
19
18
17
16
15
14
13
12
16

divided into inches over a considerable range so as to facilitate the taking of readings. You will observe that the blade commences at about 18 inches from the centre of the shaft, but it is generally conceded that even as far out as 2 feet where the blade has assumed its shape, unspoiled by the curvature of the root, there is, in the case of a propeller of this diameter and pitch, very little useful effect. In fact, the author remembers attending a lecture, some seven or eight years ago, at the Institution of Civil Engineers, Westminster, where it was demonstrated by working models in operation that the inner portion of a fan blade had so little power that for all practical purposes it was a negligible quantity. The 4 feet radius has been chosen for these trials as the author imagines that to be about the centre of effort; and on this point, as well as upon the question of the useless inner third of the blade, he especially invites discussion; as he is anxious to hear what more experienced members may have to say as to their own theories and observations with reference to the subject. As to the choice of a point

TABLE

Showing variations in the Pitch of a Blade when slewed from its Normal Position, the Blade being a true screw, 16 *feet pitch and* 12 *feet diameter.*

RADIAL DISTANCES FROM CENTRE OF SHAFT.

Pitch of 4 feet radius	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet
13·	12·6	13·4	13·3½	13·0	12·7	12·1½
13·6	—	—	—	—	—	—
14·0	13·7	14·2¼	14·2¼	14·0	13·8¾	13·5¼
14·6	—	—	—	—	—	—
15·0	14·9	15·1	15·1	15·0	14·10¼	14·8¾
15·6	—	—	—	—	—	—
16·0	16·0	16·0	16·0	16·0	16·0	16·0
16·6	—	—	—	—	—	—
17·0	17·4¾	16·11¼	16·11	17·0	17·1	17·3
17·6	—	—	—	—	—	—
18·0	19·0	17·11¼	17·10¼	18·0	18·2½	18·6
18·6	—	—	—	—	—	—
19·0	20·8¾	19·0	18·10	19·0	19·4	19·8½

upon which to swing the blade, or rather the representation of its pitch lines upon paper, it would be quite possible to select *any other* point in the thwartship line as a pivot, and the results would be exactly the same, but the process would be a little more laborious. For by taking the point above mentioned, the 4 feet angle which has been chosen as a starting point, can be adjusted as required, direct—and without the trouble of ruling parallels.

It would occupy a needless amount of time to go over in detail the whole of the figures in the table referring to the diagram of results, so we will just take a couple of instances at random and try over the readings obtained. Suppose we take two new positions intermediate with those of the Table, say 14 feet 6 inches and 17 feet 6 inches, or 18 inches below and above normal. Take the lower one first. We take the 4 feet radius pitch line, turn it a little more towards the thwartship line, reducing the angle at the pivot point, until the line intersects the 14 feet 6 inches mark on the fore and aft line, which corresponds to the advance of the vessel due, to one revolution of the propeller (neglecting "slip").

Now we want to know what is the pitch of the blade at the other points on its surface, foot by foot, from the one foot radius which is smothered up in the structure of the boss, right away out to the tip.

You will observe that the pivot line is the only one which correctly intersects the thwartship line, all the others cut it at the points which do not correspond with the distance they travel in a revolution, and before we can read off the pitch on the other lines, we must correct them by ruling parallels which *do* cut the required positions.

Having done this we find that :—

		Feet	Inches
The 1 foot line has a pitch of	...	14	2
" 2 " "	...	14	8
" 3 " "	...	14	$7\frac{3}{4}$
" 4 " "	...	14	6
" 5 " "	...	14	4
" 6 " "	...	14	1

Taking the other example and working it out similarly we find that :—

		Feet	Inches
The 1 foot line has a pitch of	...	18	3
" 2 " "	...	17	6
" 3 " "	...	17	5
" 4 " "	...	17	6
" 5 " "	...	17	$8\frac{1}{2}$
" 6 " "	...	18	0

By plotting these points on the diagram of results and joining them

up by straight lines, we get a rough representation of the fluctuation in the pitch of the blade as it now stands, and it is evident that the wavy line so obtained helps to verify the lines immediately below and above it.

If any one has any doubts as to the substantial accuracy of the readings given on the table and plotted on the diagram, he may easily check them for himself and run through the whole table in a couple of hours' time, after making for himself a similar pair of pitch diagrams on a smaller and more handy scale.

In making this diagram the author has not taken sufficient readings to enable him to plot a fair curve, but it will be clear to all that straight lines give only an approximate representation of the truth ; and that a curve is what really results.

Turning now to a general consideration of the examples before us, you will see that each line on the diagram, below normal, has an elevation, and each line above normal has a depression. A little further investigation showed the author that when the lines are properly reduced to curve form, the extremity of this elevation or depression corresponds to that portion of the blade which, for the time being, lies at an angle of 45 degrees. And it appears reasonable to conclude that on the inside of that position the blade is practically useless, as the direction in which it exerts it energy is more in a centrifugal than in a fore and aft direction ; whilst outside of that position the centrifugal action diminishes, and the useful fore and aft action becomes more pronounced. Perhaps it may be interesting to show that the angle of 45 degrees lies, in all true screw blades, at a distance from the centre of the shaft which may be found by dividing the pitch of the blade by 6·2832 or $2 \times \pi$. This can be easily proved by drawing a line at an angle of 45 degrees from any point on the pitch line until it cuts the thwartship line, when the radial distance can be read off by scale and will be found to be that above stated.

The author is quite prepared to admit that the whole of this investigation might have been conducted trigonometrically, but it appears to him that the graphic method gives a more ready means of arriving at the desired result, and is, at the same time, more striking and more convincing. Nevertheless he will just mention that if you measure the angle of any intersection on the thwartship line, you have only to multiply its tangent by the length of the circular path of this portion of the blade, and the product is the pitch. As for instance, in the blade before us, the angle of the 5 feet line is 27 degrees from the thwartship line as nearly as can be measured with an ordinary

protractor; the tan. of 27 degrees = ·50952 and the circular path = Rad. × 2 × 3·1416, or in this case 5 × 2 × 3·1416 = 31·416 then 31·416 × ·50952 = 16·00708, which is as near as needs be to the pitch of the propeller.

If you take the length of the path 31·416 and divide it by the Cotan. of 27 degrees, viz.: 1·9626 the result is the same, *i.e.*—

$$\frac{\cdot 31\cdot 416}{1\cdot 9626} = 16\cdot 0073.$$

This gives us a formula upon which to make a pitchometer of the protractor type as follows:—

$$\text{Tan.} \times \text{Rad.} \times 2 \times \pi = \text{Pitch.}$$

$$\text{or } \frac{\text{Rad.} \times 2 \times \pi}{\text{Cotan.}} = \text{Pitch.}$$

As to the angle through which a blade must be turned in order to effect any given variation, the author has endeavoured to make this clear by dividing off into degrees a portion of a circle, of the same diameter as the marking out circle of the stud holes; and by showing a stud hole on the drawing and on the tracing, you see at once the number of degrees travelled and the amount of slotting required to effect the desired alteration. The author will not undertake to formulate theories or draw authoritative conclusions as to the practice which Engineers may be expected to adopt from a study of this subject, he shall only simply point out that assuming the true screw to be a desirable form of blade, then any attempt to tamper with the pitch by slewing blades upon the boss gives rise, at once, to a state of things in which the intention of the designer is completely frustrated.

Within narrow limits it is true the variation is not striking, but when carried to any considerable extent, the result is peculiar, to say the least of it.

Should any Engineer desire a little increase of pitch towards the tip of the blade he may see here a means of arriving at the desired end by designing a blade of true screw form and then setting it on the boss at an angle slightly in excess of that corresponding to its true screw position. But he will also have an increase of pitch towards the root which is highly objectionable. The author is not aware that the subject has up to now been discussed by this Society, and he does not remember to have seen any reduction of results to diagram form such as he now offers you, and that must be his excuse for asking you to give time and consideration to a matter which however interesting to him may not be of any great interest to his hearers, and does not possess the charm of novelty.

DISCUSSION.

Mr. H. W. Wilson said—I might say one or two words with reference to fans. I think the author is referring, on page 377, to the paper read by Mr. Walker, of Bristol, before the Institution of Civil Engineers some years ago. Mr. Walker made a number of experiments which were not very accurately carried out, although he got some rather interesting results. Mr. Wilson

I do not know much about the action of propellers in water, but I take it that the author means that the inner portion of the propeller does not have very much effect in driving the ship forward. Now, in the best types of propeller fans designed you get results which have some bearing on this, and some of the particulars may be of interest. In almost all types of propeller fans working against a pressure you get a negative flow through the central portion of the blade, and this appears to be due to the fact that the lineal speed at which this portion of the fan is travelling is not sufficient to give a velocity to the air which will overcome the back pressure. In the most efficient type of propeller fans made you get a velocity forward of the air equal to, or rather greater than, the velocity of the portion of the blade which is propelling the air forward, but this of course represents the best results that can be obtained. As you approach the centre of the blade its lineal velocity diminishes and consequently the velocity of the air at this part also diminishes. As a condition of this kind will obtain in water also, it appears reasonable to assume that the central portion of the screw propeller has little effect in driving the vessel forward through the water.

With a fan about two feet diameter and running at a tip speed of about 6,000 to 6,500 feet per minute, the speed of the air driven backward from the tip is about 6,000 feet, but as you approach the centre of the blade the speed falls off to nothing, or there may even be a flow in the reverse direction.

The author has said a good deal about the angle at which the propeller is set on the boss, more particularly with regard to the conditions that exist when this angle is 45 degrees. Mr. Walker in his experiments stated that they found that for fans the best results were generally obtained when the blade was set on the boss at an angle of 40 degrees, though he seemed to consider that the best angle varied according to the number of blades employed. One of the leading firms of fan makers in the country, however, invariably set their fan blades at 45 degrees.

Mr. Wilson

In his paper the author has made no comments as to the effect which a varying thickness of the blade has upon the performance of screw propellers, and I should be glad if he would make some remarks upon this subject in his reply. With fans it has been found by experience that the thickness of the blade has a considerable effect upon the results obtained, and I understand that the same thing holds good with regard to screw propellers.

Mr. Kirkpatrick

Mr. W. D. Kirkpatrick said—I should like to ask the author if he considers that where two or more propellers are fitted on the same shaft, they should be of the same pitch or different pitches? If similar, should the forward ones be placed in such a position on the shaft relative to the after ones as to form a true screw in order to obtain the most efficient result?

Then, as to form of blades, from some experiments I have made on a model torpedo boat destroyer I find that the large superficial area blades, with an increasing pitch, appear to give the most satisfactory speed results. Unfortunately it was not possible to measure the power in this case, and it is only fair to say that the model used has a modified form of hull in order to accommodate workable machinery. I might add that the speed of this model was considerably increased when two hollow bladed propellers were used, which were arranged so as to form a true screw.

Mr, Houghton

Mr. H. J. Houghton said—The author stated that the inner portion of the propeller blade for about one third the distance from the root was of very little use. This third part was done away with on the propeller of a destroyer, a stalk connecting the boss to the blade, it was then found that this propeller was not so efficient as the ordinary type. So it seems to me that this inner third portion is of use after all, as in the case stated, it was found impossible to obtain more than $25\frac{1}{4}$ knots, whereas with an ordinary propeller 25·6 was obtained.

Although it is admitted that the inner portion of the blade is not so efficient as the outer part, still as it apparently does useful work it would seem advisable to retain it.

Mr. Young

Mr. J. Denholm Young said—The subject of the paper is an important one, and the author is doing service to marine engineers in reminding them that when they twist round the blades of a propeller the pitch is not uniformly decreased or increased.

The general problem has already engaged the attention of technical writers, and those who wish fuller information on the subject will find it mentioned in Durand's "Resistance and Propulsion of Ships," also in D. W. Taylor's book on the same subject. A table of factors

is given in both of these works for the reduction of the original pitch to actual pitch after twisting of the blade, for various angles and various pitch-ratios. Mr. Young

Also in the 1903 volume of the Trans. I.N.A. will be found a paper by Professor Scribanti giving very complete tables for the same purpose, to the discussion of which, Mr. McFarlane Gray contributed a generalized diagram, similar to the particular diagram given by Mr. Crump.

It would be of interest to those members in the marine profession if the author would give some of the experimental results obtained with twisted blades.

Mr. J. B. Brew said—I quite agree with the author of the paper in his assertion that the pitch of a propeller blade can be altered to a limited extent only. The propeller being cast on a bed struck up to the true pitch required the blade takes its own particular form for that pitch and diameter. Afterwards, if any alteration is made to the correct fore and aft-line for that true pitch, the blade, I might say, becomes distorted and gives the results shown by the author. It is very seldom that the slotted stud holes are made to give a greater variation than a foot less and a foot greater than the true pitch of the blade. Mr. Brew

The pitch being altered at the centre of effort (say) one foot, the difference of the resultant from the various pitches inside and outside the point set to the desired pitch would be such as to affect the results to a very small degree.

As regards the usefulness of the inner third of the blade, I think it has been conclusively proved that it is of little or no use for propelling purposes.

There were some experiments made in the Mersey some little time ago with a propeller having the centre or boss so made that it filled up one third the propeller area. The stern post and rudder post were made up to suit the increased diameter of the boss so as to give a clear run for the water.

Several propellers have since been made of this design from the data of above experiments, and have given, I am led to understand, improved results over the ordinary propeller.

Mr. A. H. Crump, in reply, said—Mr. Wilson spoke of the difference in design between "air" fans and propellers. Now, there is just this difference, that although I have seen many air fans of the propeller type, I never saw one in which there was a real effort made to assimilate the blade to the true screw form. There is, undoubtedly, Mr. Crump

Mr. Crump some twisting of the blade whereby the blade departs from the form of plane, but I have never seen one in which the blade assumed the form of a true screw.

A blade, of the same shape as that of an average air propeller, would result in 50 or 60 per cent. of slip, if used for driving a vessel, and the churning action would be so pronounced as to absorb the greater part of the horse power.

As to the number of blades, I do not think it makes much difference provided the blades are not too numerous. I did not touch on this in my paper, because I did not intend to go into the subject, but the experience has been that you *may* do badly with four blades, while you *might* do very well with three.

Then, with regard to the thickness of the blade, and the possible effect that thickness might have upon its working, I may say that the endeavour of all propeller designers is to keep down thickness, and to get a nice run on the trailing edge of the blade, but it is the working face of the blade—that is, the after face of the blade—which is designed to be of true screw form, and the forward surface of the blade is bound to depart from true screw form, in order to get a backbone on the blade and thin edges.

The forward surface of the blade which is not doing work on the water is sacrificed in order that the after surface may be of true screw form.

None of the speakers have challenged the desirability of obtaining a true screw form. In fact, the remarks tend to confirm the general opinion that it is the best form, except, I think, the remarks of Mr. Kirkpatrick, who made mention of using some blades in which he had an increasing pitch. You will see from my paper that this may be adopted by some engineers, and blades have been designed which have an increase of pitch towards the following edge of the blade. That is a very different thing from getting a line like this.

Then as to the uselessness of the middle-third of the blade, Mr. Houghton reminded me of an experiment that was made—I have heard of it before—in which a blade was planted upon a stalk, and I am rather inclined to think that if the thing were looked into still more carefully it would be found that the stalk was the cause of the insufficiency of the blade; but whether the inner-third may have a value or not, we are agreed that, square inch for square inch, it has nothing like the value of the portion of the blade which lies at an angle of 45 degrees.

LIVERPOOL ENGINEERING SOCIETY.

THIRTIETH SESSION.

ANNUAL GENERAL MEETING—27TH APRIL, 1904.

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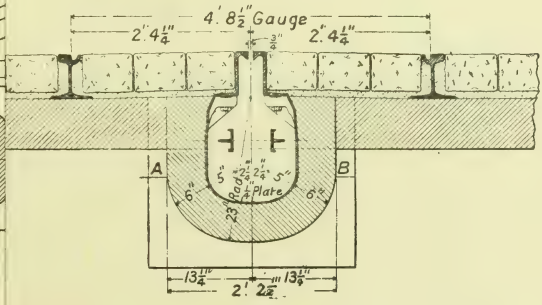

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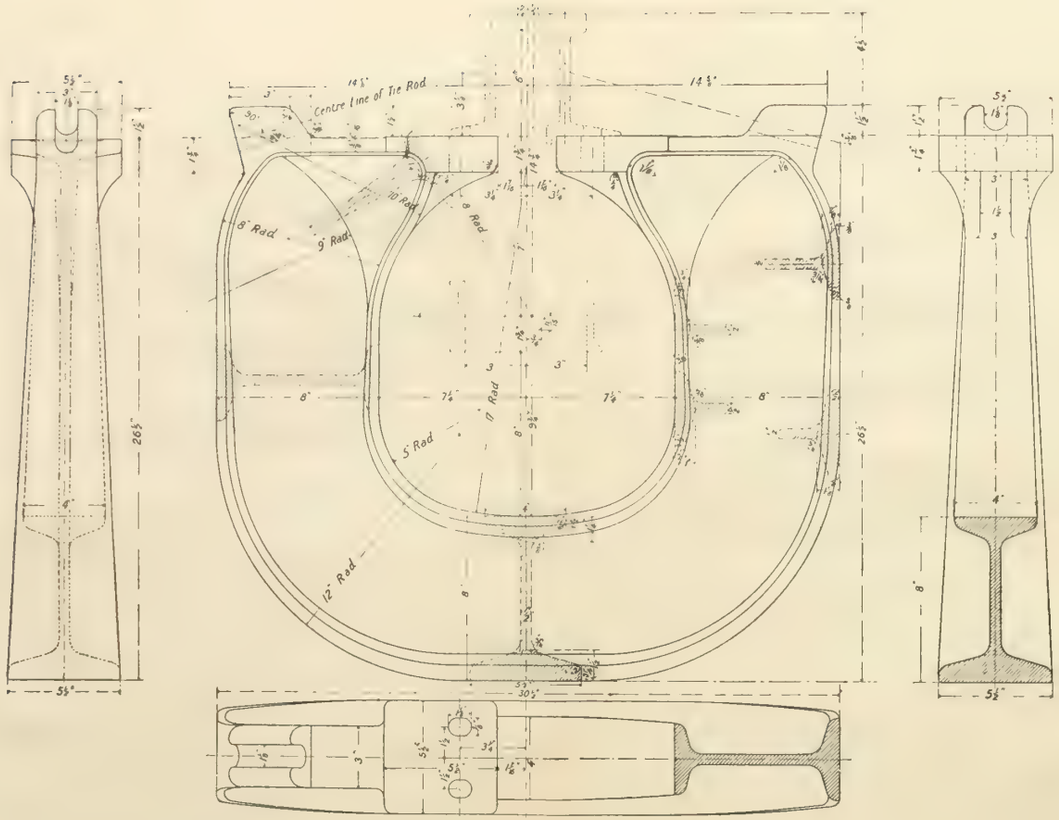

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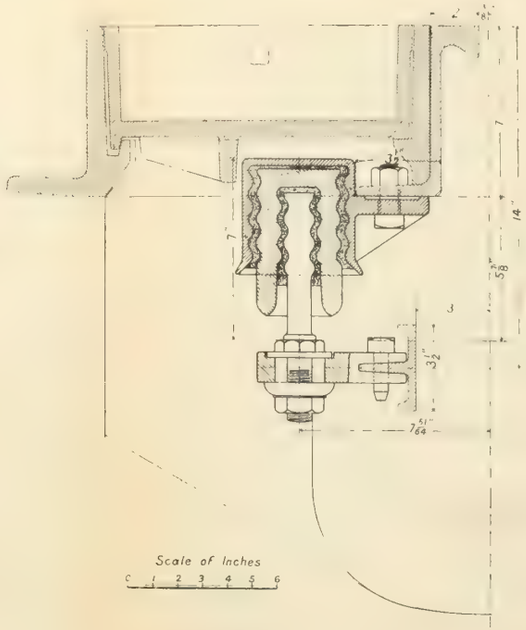

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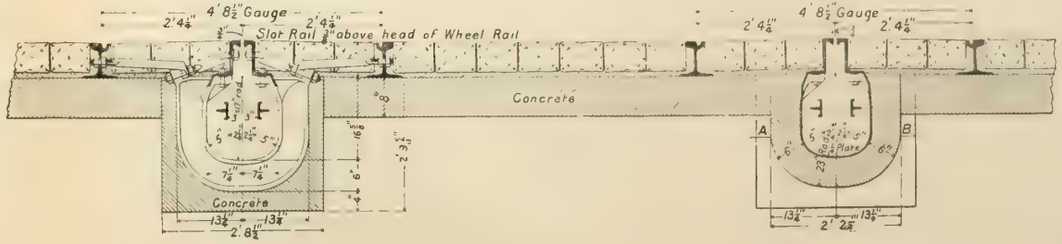

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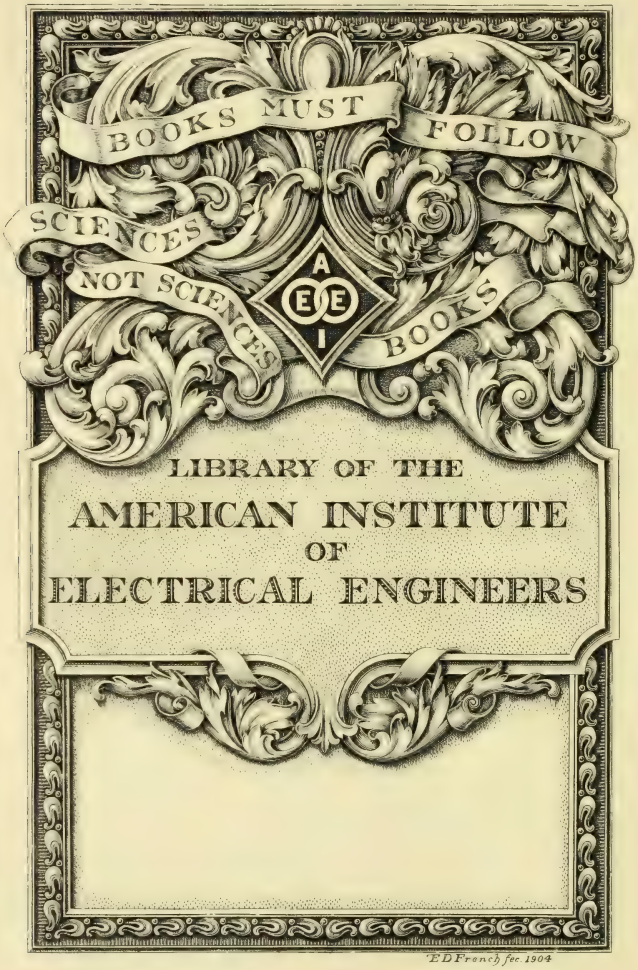
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LIVERPOOL ENGINEERING SOCIETY,

ROYAL INSTITUTION, COLQUITT STREET.

XXXI SESSION.—1904-1905.

(From the 2nd November, 1904, to the 26th April, 1905.)

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ARTHUR R. T. WOODS, M. I. N. A.

Past-Presidents.

In accordance with Rule IV, the following Past-Presidents are ex-officio Members of Council for five consecutive years after their retirement from Office.

JOHN A. F. ASPINALL, M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst., 1900-1901.

ARTHUR MUSKER, M. Inst. C.E., M.I. Mech. E., 1901-1902.

ERNEST S. WILCOX, M. Inst. C.E., 1902-1903.

THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E., 1903-1904.

FRANK E. PRIEST, M. Inst. C.E., 1904-1905.

Honorary Solicitor.

ERNEST W. PIERCE,
Deputy Town Clerk, Municipal Buildings, Liverpool.

Honorary Librarian.

ALARIC HOPE, Assoc. M. Inst. C.E., A.M.I. Mech. E.,
Dock Yard, Liverpool.

Honorary Treasurer.

COARD S. PAIN, Assoc. Inst. C.E., F.S.I.,
14, North John Street, Liverpool.

Honorary Secretary.

R. C. F. ANNETT, Assoc. Inst. C.E.,
4, Buckingham Avenue, Sefton Park, Liverpool.

NOTE.—In accordance with Rule V, the above Council continues in Office until the first Wednesday in November, 1906.

LIVERPOOL ENGINEERING SOCIETY.

Past-Presidents of the Society.

(1.)	1875-76 / 1877	C. Henry Graham Smith, Assoc. M. Inst. C.E.	(Died 9th Sept., 1884). See Memoir in Vol. LXXVIII. Proc. Inst. C.E.
(2.)	1878	Robinson Souttar, M.P., M.A., B.C.L. Oxon.	
(3.)	1879	M. E. Yeatman, M.A. Cantab., M. Am. Soc. C.E.	
(4.)	1880	Alexander Ross, M. Inst. C.E.	
(5.)	1881	Alfred Holt, M. Inst. C.E.	
(6.)	1882	Frank B. Salmon, M.I. and S. Inst.	
(7.)	1883	Henry Bramall, M. Inst. C.E.	
(8.)	1884	R. Ratsey Bevis, Junr., M. Inst. C.E.	
(9.)	1885	William E. Mills, F.S.I.	
(10.)	1886	Coard S. Pain, Assoc. Inst. C.E., F.S.I.	
(11.)	1887	John J. Webster, M. Inst. C.E.	
(12.)	1888	Chas. H. Darbishire, J.P., Assoc. M. Inst. C.E.	
(13.)	1889-90	Henry H. West, M. Inst. C.E., M. I. N. A., M. I. Mech. E.	
(14.)	1890-91	Ferdinand Hudleston, M. Inst. C.E.	
(15.)	1891-92	John T. Wood, M. Inst. C.E.	
(16.)	1892-93	Robert E. Johnston, M. Inst. C. E.	
(17.)	1893-94	H. Percy Boulnois, M. Inst. C.E., F.S.I.	
(18.)	1894-95	H. S. Hele-Shaw, LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M. I. Mech. E., F.R. Met. Soc.	
(19.)	1895-96	Arthur J. Maginnis, M. I. N. A., M. I. Mar. E.	
(20.)	1896-97	S. B. Cottrell, M. Inst. C.E., M.I. Mech. E.	
(21.)	1897-98	George Farren, J.P., M. Inst. C.E., F.R.S.S.	(Died 10th April, 1901). See Memoir in Proc. Inst. C.E.
(22.)	1898-99	John A. Brodie, Wh. Sc., M. Inst. C.E., M.I. Mech. E.	
(23.)	1899-00	A. Bromley Holmes, M. Inst. C.E., M.I.E.E.	
(24.)	1900-01	John A. F. Aspinall, M. Inst. C.E., M.I. Mech. E., M.I. and S. Inst.	
(25.)	1901-02	Arthur Musker, M. Inst. C.E., M.I. Mech. E.	
(26.)	1902-03	Ernest S. Wilcox, M. Inst. C.E.	
(27.)	1903-04	Thomas L. Miller, M. Inst. C.E., M.I. Mech. E., M.I.E.E.	
(28.)	1904-05	Frank E. Priest, M. Inst. C.E.	

Mr. FRANK E. PRIEST, M. Inst. C.E.,

President of the Liverpool Engineering Society,

XXXI Session—1904-1905.

LIVERPOOL ENGINEERING SOCIETY.

REPORT.—XXXI SESSION.

1904-1905.

(From 2nd November, 1904, *to 26th April,* 1905.*)*

President:—FRANK E. PRIEST,

M. Inst. C.E.

At the close of the Thirty-first Session the retiring Council presents the following Report upon the state of the Society.

THE ROLL OF THE SOCIETY.

The additions to the Roll of the Society at the close of the Annual Meeting on the 26th April, 1905, have been 42 compared with 40 in the previous Session, comprising 27 Members, 5 Associate Members, 4 Associates and 6 Students.

On the other hand, it has to be recorded that 46 names have been removed from the list as against 19 last year. 18 of these were due to resignation, 25 were struck off the roll and 3 were due to death. One transfer from the Associate Class to Membership took place during the Session, besides 2 transfers from Student Class to Associate Member Class. At the present date the number of Members of all classes is 528; being 9 Honorary Members, 10 Life Members, 1 Life Associate, 411 Ordinary Members, 17 Associate Members, 54 Associates and 26 Students.

THE SESSION AND MEETINGS.

The present Session was opened on the 2nd November, 1904, by the President, Mr. Frank E. Priest, M. Inst. C.E., who delivered his Inaugural Address before a full audience of Members and their friends.

Beginning with a reference to Engineers of mediæval times, he proceeded to trace the interdependence of civilisation and Engineering, particularly with reference to the disposal of sewage.

Although the difficulties arising from the accumulation of sewage were experienced continually, it was pointed out that up to the middle of the 19th century practically no progress had been made at systematic sewering, and by extracts from the first report of the Commissioners for enquiring into the state of large towns and populous districts, issued in 1844, the terrible state in which the large towns of the country were existing was shown.

The President further stated the very high death-rate that prevailed at the time, and instanced that of Liverpool, which amounted to 35 per 1000 during the years 1840 and 1842.

He then showed the several efforts towards mitigating the evil by enquiries by Royal Commissions, and by Acts of Parliament, and described several of the methods which had been tried for effecting the purification of sewage.

The long struggle between the advocates of chemical treatment and irrigation and land filtration was referred to, and the more recent endeavours to effect purification by means of artificial filtrating materials were also recounted, and finally the introduction of biological methods was traced from its origin in the discoveries of Kircher and Leuwenhoek in the latter half of the 17th century.

The experiments carried out by the Massachusetts State Board of Health, by Mr. Dibdin at Barking, by Mr. Cameron at Exeter, and by Mr. Scott-Moncrieff, were commented upon, and the nature of the process by which the purification is effected was mentioned, with some facts as to the organisms effecting it. The enormous influence of the all-powerful means which Nature has provided for the destruction of the animal and vegetable waste of her kingdom were pointed out, and congratulation was offered that at last we were beginning to understand something of the matter, although our knowledge had progressed only to the verge of the subject.

The consideration being given to the subject of sewage treatment by the Royal Commission now sitting, and the voluminous reports being issued by the Commission, were referred to.

This was succeeded at subsequent meetings by papers and discussions upon the various Engineering subjects enumerated in the following summary :—

1904.

16th November.—Mr. E. Allen, M.I. Gas E.
"Some Engineering Problems in Gas Works."

30th November.—Mr. S. H. Ellis, Assoc. M. Inst. C.E.
"Notes on some Hydraulic Limes."

14th December.—Mr. T. Molyneux.
"Heavy Motor Vehicles."

1905.

11th January.—Mr. J. Grundy, M.I.N.A.
"Ship and Engine Equipment."

25th January.—Mr. F. W. Steele.
"Design and Work of Hydraulic Pressing, Stamping, Forging and Similar Machinery."

8th February.—Mr. T. Duncanson, M. Inst. C.E.
"Flow of Water in Pipes, Channels and Rivers."

22nd February.—Mr. Fielden Sutcliffe.
"Sundry Notes on Dock Construction."

8th March.—Adjourned Discussion on Mr. Sutcliffe's Paper.

22nd March.—Mr. H. W. Wilson, A.M.I.E.E.
"Electrification of Railways."

5th April.—Adjourned Discussion on Mr. Wilson's Paper.

26th April.—Annual General Meeting.

Announcement of Election of Council and Officers.

Report of Council for the 31st Session.

Honorary Treasurer's Annual Statement of Receipts and Expenditure for the previous year.

Presentation by the President of the Diploma Certificates to those Members, Associate Members, Associates and Students who have been elected to the Society during the Past Session.

Paper by Mr. A. F. Fowler, M. Inst. C.E., M.I. Mech. E., entitled :—"The Evolution of Harbour Engineering."

Appointment of Auditor for Session 1905-1906 (in accordance with Rule VI).

DERBY GOLD MEDAL.

The Derby Gold Medal for the 1903-1904 Session was awarded to Mr. Louis J. Hunt, Assoc. M. Inst. C.E., A.M.I.E.E., *Member*, for his paper entitled :—"Notes on Design of Electrical Machinery," read before the Society on the 23rd March, 1904.

SOCIETY'S PREMIUM.

The Society's Premium for the same Session was awarded by the Council to Mr. H. S. Meyer, M.I.E.E., *Member*, for his paper entitled :—"Voltage Regulation in Alternating Current Systems," read before the Society on the 20th January, 1904.

Both of these presentations were made by the President on the 25th January, 1905.

DERBY GOLD MEDAL.

The following are the terms and conditions agreed to in connection with the award of this medal:—

1.—The Medal to be called the DERBY GOLD MEDAL.

2.—The Medal to be awarded annually to the author of any paper read during the Session which a Special Committee, appointed by the Council, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council), and the Honorary Officers of the Society, may select as most worthy of such distinction.

3.—The Members of the Committee at a meeting called for the purpose, shall express their selection by vote, and in case of equality of votes the Chairman shall have a casting vote.

4.—No Member of the Committee having himself read a paper during the Session shall take part in the adjudication.

SOCIETY'S PREMIUM.

The following are the conditions as to the award of this premium:—

1.—That the Special Committee, consisting of the President, three preceding Past Presidents (ex-officio Members of the Council) and the Honorary Officers of the Society appointed to award the DERBY GOLD MEDAL be requested to make a recommendation annually to the Council as to the award of the Society's premium to the author or authors of any paper or papers read during the previous Session which the Committee may consider worthy of such recognition.

2.—No paper, the author of which is a Member of the Council or for which the DERBY GOLD MEDAL is awarded shall be eligible for the Society's premium.

3.—The premium shall, subject to the approval of the Council in each case, be presented in the form of books or other articles which may be selected by the author of the paper as useful to him in his profession.

4.—The value of the premium shall in any year be such sum as the Council may prescribe not exceeding the sum which shall have accrued from the investment of the Society's premium fund and to be available for the purpose.

EXCURSIONS.

By the courtesy and kindness of the respective Companies concerned, members were enabled to visit and inspect the following works, viz.:—

The British Westinghouse Electric and Manufacturing Company's Works at Trafford Park, Manchester.

The Works of Messrs. Crossley Bros., Ltd., Openshaw, Manchester.

The Lancashire and Yorkshire Railway Company's Liverpool and Southport Electric Railway and Works.

The thanks of the Council have been duly conveyed to the respective authorities.

ANNUAL DINNER.

The Annual Dinner of the Society took place at the Adelphi Hotel, Liverpool, on the evening of Thursday, the 19th January, 1905.

About 160 Members and their friends supported the President on that occasion.

The Society's guests included amongst others: The Lord Mayor of Liverpool (Right Hon. John Lea); His Worship the Mayor of Birkenhead (E. W. Crosbie Oates, Esq.); The United States Consul (Hon. James Boyle); The Chairman of the Liverpool Water Committee (Alderman W. J. Burgess, J.P.); The President of the Manchester Association of Students of Civil Engineers (Hubert Congreve, Esq.); The Chairman of the Manchester Section of the Institution of Electrical Engineers (Chas. D. Taite, Esq.); Charles McArthur Esq., M.P.; The President of the Incorporated Law Society (Arnold J. Cleaver, Esq.); The Secretary of the Liverpool University Student Engineering Society (G. W. Worrall, Esq.); Sir H. Seton-Karr, M.P.; Rev. Dr. John Watson; The Secretary of the Institution of Civil Engineers (Dr. J. H. T. Tudsbery).

OBITUARY.

It is with deep regret that the Council record the death, during the Session, of Mr. Reginald W. Armistead, the late Honorary Librarian. Mr. Armistead in his association with the Council spared no efforts to promote the interests of the Society, and, in his capacity as Honorary Librarian, worked with enthusiastic zeal for the benefit of the members. His early decease is much to be deplored.

The Council also regret to announce the death of Mr. Thomas M. Bigley, Assoc. M. Inst. C.E. (Member), and Mr. S. W. Higginbottom, C.C. (Associate).

RECEIPTS AND EXPENDITURE.

In accordance with Rule VI, the Honorary Treasurer's Financial Statement of Accounts for the Year ended 31st December, 1904, has been duly audited by Mr. F. W. Marsh, C.A., and is presented herewith. (See page xiii.)

GROWTH OF THE SOCIETY.

The following Table shows the progress made by the Society since its commencement in 1875:—

Year	Honorary Members	Ordinary Members	Associate Members	Associates	Students	Total	New Members Elected	Deaths, Resignations, Transfers, &c.	Nett Increase	President for each Session
1875-76	—	51	—	—	—	51	—	—	—	C. H. Graham Smith
1877	3	68	—	—	—	71	20	—	20	
1878	3	82	—	—	—	85	17	3	14	Robinson Souttar
1879	3	73	—	—	—	76	4	13	—	M. E. Yeatman
1880	3	88	—	—	—	91	23	8	15	Alexander Ross
1881	4	93	—	—	—	97	18	12	6	Alfred Holt
1882	5	88	—	—	11	104	10	3	7	Frank B. Salmon
1883	5	96	—	—	8	109	10	5	5	Henry Bramall
1884	5	99	—	—	6	110	16	15	1	R. Ratsey Bevis
1885	5	109	—	—	4	118	19	11	8	William E. Mills
1886	5	120	—	—	11	136	28	10	18	Coard S. Pain
1887	7	144	—	—	15	166	32	2	30	John J. Webster
1888	6	151	—	—	18	175	30	21	9	C. H. Darbishire
1889-90	6	169	—	1	16	192	33	16	17	Henry H. West
1890-91	6	181	—	3	9	199	20	13	7	F. Hudleston
1891-92	5	191	—	6	11	213	19	5	14	John T. Wood
1892-93	3	219	—	8	10	240	35	8	27	R. E. Johnston
1893-94	2	221	—	11	13	247	29	22	7	H. P. Boulnois
1894-95	4	238	—	11	21	274	41	14	27	H. S. Hele-Shaw
1895-96	6	278	—	18	20	322	61	13	48	A. J. Maginnis
1896-97	8	311	—	25	19	363	49	8	41	S. B. Cottrell
1897-98	10	325	—	28	20	383	26	6	20	George Farren
1898-99	10	338	—	33	21	402	45	26	19	John A. Brodie
1899-00	10	416	—	55	21	502	119	19	100	A. Bromley Holmes
1900-01	10	425	—	59	24	518	27	11	16	J. A. F. Aspinall
1901-02	10	396	—	59	18	483	38	73	—	Arthur Musker
1902-03	9	417	8	63	18	515	43	16	27	Ernest S. Wilcox
1903-04	9	434	11	59	22	535	40	20	20	Thomas L. Miller
1904-05	9	421	17	55	26	528	42	49	—	Frank E. Priest

THE LIBRARY.

The following publications have been received during the year:—

From the editors and proprietors—"British Architect"; "Cassier's Magazine"; "Engineer's Gazette"; "Fielden's Magazine"; "Indian Engineering"; "Mechanical Engineer"; "Page's Magazine"; "Public Health Engineer"; "The Traveller"; "The Ironmonger."

And also — "Annual Report, Chief of Engineers," U.S. Army; "Annual Report, Chief of Bureau of Steam Engineering, U.S.A."; "Trans. Incorporated Gas Institute"; "The Sanitary Inspector"; "Annual Report of the Chief Engineer of the Liverpool Water Works"; Technology Quarterly (Boston, U.S.A.); "Annual Report of the Manager of the Liverpool Corporation Tramways."

The Society exchanges Transactions with—

1. American Association for the Advancement of Science
2. American Institution of Electrical Engineers
3. American Institution of Mining Engineers
4. American Society of Civil Engineers
5. American Society of Mechanical Engineers
6. Association of Engineering Societies
7. Western Society of Engineers
8. British Association for the Advancement of Science
9. British Association of Waterworks Engineers.
10. Canadian Society of Civil Engineers
11. Civil and Mechanical Engineers' Society
12. École d'application du Genie Maritime, Paris
13. Engineers' Club of Philadelphia
14. Engineering Society Western Pennsylvania
15. Franklin Institute
16. Incorporated Gas Institute
17. Institute of Marine Engineers
18. Institution of Civil Engineers
19. Institution of Electrical Engineers
20. Institution of Engineers and Shipbuilders in Scotland
21. Institution of Mechanical Engineers
22. Institution of Naval Architects
23. Iron and Steel Institute
24. Junior Inst. of Engineers
25. Liverpool Architectural Society
26. Liverpool Philomathic Society
27. Manchester Association of Engineers
28. Manchester Literary and Philosophical Society
29. Midland Counties Institution of Engineers
30. Midland Institute of Mining, Civil and Mechanical Engineers
31. Mining Institute of Scotland
32. North-East Coast Institution of Engineers and Shipbuilders
33. North of England Institute of Mining and Mechanical Engineers
34. North Western Sanitary Inspectors' Association.
35. Philadelphia Commercial Museum
36. Royal Institution of Cornwall
37. Royal Philosophical Society of Glasgow
38. Royal Physical Society of Edinburgh
39. Smithsonian Institution
40. Society of Architects
41. Society of Arts of the Massachusetts Institute of Technology
42. Society of Engineers
43. South Wales Institute of Engineers
44. Stevens Institute of Technology
45. University of California
46. Yorkshire College Engineering Society

The Transactions of the Society are presented to—

47. "American Engineer and Railroad Journal"
48. Bootle Free Public Library
49. "British Architect"
50. Chief of Engineers U.S. Army
51. "Engineer"
52. "Engineering"
53. Engineering Department, Liverpool University
54. "Fielden's Magazine"
55. "Indian Engineering"
56. Liverpool Free Public Library
57. "Mechanical Engineer"
58. McGill University, Montreal
59. Patent Office Library
60. Society of Arts
61. University of Minnesota

Total Number of Transactions exchanged with, and presented to, other Societies = 61.

LIVERPOOL ENGINEERING SOCIETY.

Dr. STATEMENT of RECEIPTS and EXPENDITURE to the 31st DECEMBER, 1904. Cr.

RECEIPTS.

			£ s. d.
To Balance from last Account, viz. :—			
Lloyds Bank, Ltd.		£174 13 2	
Assistant Treasurer		1 1 0	
			175 14 2
" Subscriptions due 1st January, 1904—			
239 Resident Members		250 19 0	
171 Non-Resident Members		89 15 6	
7 Resident Associate Members		7 7 0	
3 Non-Resident Associate Members		1 11 6	
37 Resident Associates		38 17 0	
18 Non-Resident Associates		9 9 0	
22 Students		11 11 0	
497		409 10 0	
Add Arrears from 1903		67 5 0	
		476 15 0	
Deduct Amount received in advance in 1903..	£7 7 0		
" Arrears written off during year	31 10 0		
" " to 31st December, 1903	13 4 6		
" " to 31st December, 1904	32 11 0		
		84 12 6	
		392 2 6	
Add Amount received for 1905		9 9 0	
			401 11 6
" Proceeds—Sale of Transactions, £2/10/0, and Journals, £1/6/8			3 16 8
" Bank Interest, £4/14/11 ; less Commission, 14/6			4 0 5
" Dividends on £150 L. & Y. Railway 3% Debenture stock			4 5 9
" " £250 Midland Railway 2½% Pref. stock			5 19 2
" Lord Derby for Gold Medal		10 0 0	
Oldfields, Ltd.—Cost of Medal		9 9 0	
			0 11 0
Total			£595 18 8

EXPENDITURE.

		£ s. d.
By Royal Institution Rent to February 14th, 1904	£20 0 0	
" " " Hire of Bookcase	1 1 0	
		21 1 0
" " " Attendant to 14th Sept., 1904		3 0 0
" Postages and Sundries, including hospitality to the Members of the Manchester Society		13 14 7
" Stationery, Postages, Notices, Transactions, Official Books, &c.		40 0 0
" General Printing—Notices of Meetings, Dinner, Excursions, Annual Reports, &c.		58 12 10
" Printing, Illustrating, and Binding Transactions (Volume XXV), (including Postages, &c.)		165 19 7
" Annual Dinner, 1904—		
Hotel Account, &c.	£192 0 2	
Less Proceeds of Tickets Sold	152 5 0	
		39 15 2
" Assistant Secretaries to 31st December, 1904		52 10 0
" " Treasurer to 29th April, 1904		15 15 0
" Audit Fee to 31st December, 1903		3 3 0
" Cost of £100 Great Western Railway Consolidated Ordinary Stock		141 10 6
" Premium Account—Transfer		5 4 0
" Balance in Lloyds Bank, Ltd.		35 13 0
Investment Account—		
£150 Lanc. & York. Rly. 3% Deb. stock cost	£169 12 0	
£250 Midland Rly. 2½% Pref. stock cost	202 12 2	
£100 Great Western Rly. Consol. Ord. stock cost..	141 10 6	
	£513 14 8	
Total		£595 18 8

I have examined this Account with the Books and Accounts of the Society, and certify the same to be correct.

I have ascertained that the Certificate of the Debenture and Preference Stock as mentioned above are deposited with Lloyds Bank, Limited, Liverpool, and I have further verified the Balance at the Bankers.

Liverpool, 10th March, 1905 (Signed) FRED. W. MARSH, Chartered Accountant.

LIVERPOOL ENGINEERING SOCIETY.

PERMANENT PREMIUM FUND, as at 31st DECEMBER, 1904.

Dr. | **Cr.**

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance from last Account...	1	19	9	By 5th Premium—Mr. F. J. Haswell (Session 1902-1903)... ...	5	4	0
" General Account—Amount withdrawn ...	5	4	0	" Balance in Lloyds Bank	1	19	9
	£7	3	9		£7	3	9

I have examined the above Account with the Books and Vouchers of the Society, and certify the same to be correct.

I have ascertained that the Certificates of the £105 North Eastern Railway Consols are deposited with Lloyds Bank, Limited, Liverpool, and I have further verified the Balance at the Bankers.

LIVERPOOL, 20*th April*, 1905.

(Signed) FRED. W. MARSH, *Chartered Accountant*

LIVERPOOL ENGINEERING SOCIETY.

ESTABLISHED 10*th* *NOVEMBER*, 1875.

Rules and Regulations.

OBJECT OF THE SOCIETY.

The promotion of the study and practice of Engineering.

RULE I.

Constitution.

The Society shall consist of Honorary Members, Members, Associate Members, Associates, and Students.

"Honorary Members" shall be men of eminent scientific attainments, elected from time to time by the Society.

"Members" shall be persons of not less than 25 years of age, who shall have been regularly educated as Engineers according to the usual routine of pupilage or apprenticeship, and who shall be actually engaged at the time of application for election in a responsible position in any branch of the profession of Engineering, or who shall, in the opinion of the Council, have attained such experience in any branch of the profession as to qualify them for Membership.

"Associate Members" shall be persons of not less than 21 years of age, who shall have been regularly educated as Engineers, and who shall, at the time of application for election, be engaged in connection with the design, construction or superintendence of some engineering work or undertaking.

Honorary Members, Members, and Associate Members, shall be entitled to all the privileges of membership of the Society, and shall be deemed to be included, where not inconsistent with the context, in the expression "member" hereafter appearing.

Associates shall be persons of not less than 21 years of age, who are not Engineers by profession, but who, by their connection with science or the arts, or otherwise, are qualified to co-operate with Engineers in the advancement of professional knowledge.

Students shall be persons under 21 years of age, in course of training to become Engineers.

"Associates" and "Students" shall have all the privileges of membership, except that they shall not be eligible for election to the Council otherwise than as Officers, and shall not have a right to take any part in the proposal or election of candidates for the Society, or to vote.

RULE II.

Election of Candidates.

Every candidate for election as a member or associate shall be proposed and recommended according to Form A in the Appendix.

Every candidate for election as a student shall be proposed and recommended according to Form B in the Appendix.

These forms being duly filled in, must be signed by at least three members certifying personal knowledge of the candidate and testifying to his qualification. In the case of the proposal of an Honorary Member the form shall be signed by a majority of the members of Council.

The Council shall examine each proposal form and shall decide whether the qualifications of the person proposed satisfy the necessary conditions for admission to the Society, and if so, in which class he is qualified to be admitted. The Honorary Secretary shall submit the proposal form to the next following Ordinary Meeting of the Society, and shall report that the proposal form has been examined and approved by the Council.

The proposal form shall be open for inspection at the meeting, and for a period of 12 days thereafter, and the candidate shall thereupon become eligible for election at the next following Ordinary Meeting of the Society.

The Honorary Secretary shall cause the names and addresses of all candidates eligible for election to the Society, with the names of their proposers and seconders, to appear on the notice convening the next Ordinary Meeting of the Society.

The election shall be by ballot, and every candidate shall be declared to be elected unless there be at least one negative vote for every three affirmative votes.

The proposal for transferring any person from the class of Associate Member to the class of Member shall be according to Form C in the Appendix. Such form shall be signed by at least six members and delivered to the Honorary Secretary, and shall be submitted to the Council, who may, if they consider the qualifications of the candidate justify such course, make the proposed transfer.

RULE III.

Residence.

Members, Associate Members, or Associates residing or being engaged in a place of business within ten miles of the Liverpool Exchange shall be considered Resident Members, Associate Members, or Associates respectively, those beyond such limits Non-resident Members, Associate Members, or Associates respectively.

Subscriptions.

The Subscription shall be, for each Resident Member, Associate Member, or Associate, One Guinea per annum; for each Non-resident Member, Associate Member, or Associate, and for each Student, Half-a-Guinea per annum.

Subscriptions shall be due and become payable on each first of January for the year ensuing, or, in the case of persons newly elected, within one month of their election, except in the case of those elected in any year during the month of November, in which case their subscriptions shall not be due until the 1st of January following.

Any Member, Associate Member, or Associate, may compound for the Annual Subscription by the payment of Ten Guineas, and so become a Life Member, Associate Member, or Associate.

Any Member, Associate Member, Associate, or Student not having paid his Subscription within three calendar months after a second notification by the Secretary that it is due, shall be reported to the Council, who may order his name to be removed from the Register of the Society.

RULE IV.

Council and Officers.

Past Presidents.

Officers.

The Council of the Society shall consist of a President, two Vice-Presidents, and twelve other members, and they, together with the following *ex-officio* members of Council, shall manage the affairs of the Society. Four shall form a quorum. Past Presidents shall be *ex-officio* members of the Council for five consecutive years after their retirement from office. The officers of the Society shall be an Honorary Solicitor, Honorary Librarian, Honorary Treasurer and Honorary Secretary, who shall be elected from amongst the Members, Associates and Students of the Society, and they shall be *ex-officio* members of the Council.

The President shall preside at all meetings of the Society and of the Council at which he is present, and shall regulate and keep order in the proceedings. President.

In the absence of the President, it shall be the duty of one of the Vice-Presidents to preside. Vice-Presidents

In the absence of the President and Vice-Presidents, the members present shall elect a Chairman to preside at the meeting.

The Honorary Solicitor shall, from time to time, give his advice to the President and members of the Council upon any legal matters arising out of the business of the Society. Honorary Solicitor.

The Honorary Librarian shall receive and be responsible for the whole of the books, papers, drawings, models, &c., belonging to the Society. He shall keep a catalogue of all such books, papers, &c., and shall lend them to the members, under regulations to be sanctioned by the Council. Honorary Librarian.

The Honorary Treasurer shall collect all sums due to the Society, and pay the same into one of the Liverpool Banks to the credit of the Society. He shall pay all sums due by the Society, by cheque, signed by two members of the Council, and keep an account of the income and expenditure in a Cash Book provided for the purpose; such Cash Book shall be open for inspection by the Council at any Council Meeting. He shall produce, at the last Council Meeting in March of each year a printed Statement of the Receipts and Expenditure for the previous year, and a Statement of Liabilities and Assets. Honorary Treasurer.

The Honorary Secretary shall act under the direction of the Council, and shall conduct the correspondence of the Society, take minutes of the Proceedings at all meetings, and enter them in the Minute Books, read the Minutes and Notices at all meetings, revise and edit the Transactions, and keep a Register of the members of the Society. Honorary Secretary.

The Honorary Officers of the Society shall be ex-officio entitled to all the privileges of membership of the Society.

RULE V.

At an Ordinary Meeting, at least two weeks before the Annual General Meeting, the Council shall present a list of persons, being members, whom they nominate as suitable for the offices of President, Vice-Presidents, members of the Council and Honorary Officers for the ensuing year, and at the same meeting the name of any member shall be added to the list on the nomination of two members present at the Meeting. Election of Council and Officers.

Such list shall include the names of not less than 12 members of the Council, exclusive of the President, 2 Vice-Presidents, and Honorary Officers.

At the Ordinary Meeting next before the Annual General Meeting, the members shall choose two or more persons as scrutineers for the purposes of the ballot. The balloting list shall immediately after the Ordinary Meeting at which it has been presented by the Council, be issued to all members in the United Kingdom, and shall be returned to the Honorary Secretary, at least three days before the Annual General Meeting, in a closed envelope, and marked "Balloting List."

The scrutineers shall open the envelopes and count the votes and report the result at the Annual General Meeting. Any balloting list on which a member has voted for a number, either more or less than one President, two Vice-Presidents, 12 members of Council, and the Honorary Officers, shall be rejected by the scrutineers.

The newly-elected Council and Officers shall take office on the first Wednesday in November, up to which date the old Council and Officers shall continue in office.

Any vacancy occurring in the Council or among the Honorary Officers during the year shall be filled up by the Council.

RULE VI.

Auditors

The Treasurer's Annual Statement of the receipts and expenditure for the previous year and his statement of liabilities and assets shall, after being duly audited by an auditor to be appointed at the preceding Annual General Meeting, be presented to the members together with the Report at the Annual General Meeting.

RULE VII.

Session and Meetings.

The Session of the Society shall commence annually on the first Wednesday in November, and terminate on the last Wednesday in April.

The Ordinary Meetings of the Society shall be held on alternate Wednesdays at Eight p.m., from November to April, inclusive, or oftener at the discretion of the Council. The Meetings shall be limited to an hour and a half's duration, but in the event of the proceedings not being completed in the hour and a half, the time may be extended, or the discussion adjourned by a vote of the Meeting.

The order of procedure at each Ordinary Meeting shall be:—

1.—The Minutes of the previous Meeting, after having been read and confirmed, shall be signed by the Chairman.

2.—Business arising out of the Minutes.

3.—Communications from the Council.

4.—Candidates for election to be announced.

5.—Candidates for election to be balloted for.

6.—Any member present for the first time since his election, having paid his subscription, and signed the Register, to be introduced by the Chairman to the Meeting.

7.—Original communications to be read and discussed.

8.—General Business.

The Annual General Meeting of the Society shall be held on the last Wednesday in April, to receive the Treasurer's Statement and the Annual Report, to appoint an auditor for the ensuing year and fix his remuneration, and to receive the Scrutineers' Report as to election of Officers and Council for the ensuing year.

RULE VIII.

Special Meetings

The Council may at any time call a Special Meeting of the Society, and shall at all times be bound to do so on the receipt of a requisition signed by not less than ten members, stating the purpose for which the Meeting is to be convened. In either case, at least seven days' notice of the time appointed by the Council for such Meeting shall be given to every member and the Meeting shall be held within twenty-one days after the receipt of the requisition. The notice shall specify the nature of the business to be transacted, and no other business shall be transacted at that Meeting.

RULE IX.

All votes on any question brought before the Society shall be given in person; except votes for the election of the Council and Honorary Officers, which shall be in accordance with Rule V. Voting.

In the event of equality of votes, the Chairman shall have a second or casting vote.

RULE X.

The Manuscript of the Papers read, or legible copies thereof, shall become the property of the Society, and shall not be published without the permission of the Council. Manuscript of Papers.

RULE XI.

Any member, associate, or student not complying with the Rules of the Society, or guilty of misconduct, may be requested by the Council to send in his resignation to the Secretary. But if he fail to do so, the Council may bring his case before a Special Meeting, who shall be entitled to expel him from the Society, or deal with the matter as they may deem expedient. Expulsion from the Society.

RULE XII.

Visitors may be admitted to an Ordinary Meeting, on the introduction of a member, associate or student, who shall enter their names in the attendance book. Visitors.

RULE XIII.

No addition to or change in these Rules shall be made except by a vote of not less than two-thirds of the members present at a Special Meeting to be convened for that purpose. Addition to, or Alteration in Rules.

APPENDIX.

[FORM A.]

Mr. ..... of .....

being of not less than twenty-$\frac{\text{one}}{\text{five}}$ years of age, born on the ..... day of .....,

and being desirous of becoming a ..... of the LIVERPOOL ENGINEERING SOCIETY, I recommend him, from personal knowledge, as in every respect worthy of election.

The candidate .....

Here specify fully such facts, with dates, *concerning the education and career of the candidate as he, or his proposer, may deem necessary to convince the members that the candidate has the proper qualifications for membership:—*

(*vide* Rule I.)

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On the above grounds I propose him to the Council as a proper person to belong to the Society.

(Signed) ..... *member.*

Date .....

We, the undersigned, concur in the above recommendation from personal knowledge and second the proposal.

.....	.....	members
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

In the event of my being elected a of this Society I hereby agree to observe and conform to all the Rules and Regulations thereof and to pay all Subscriptions and other sums which under the said Rules and Regulations shall from time to time become due from me to the Society or to any Officer thereof.

Signature of candidate .....

The Council having considered the above recommendation present ..... to be balloted for as a ..... of the LIVERPOOL ENGINEERING SOCIETY.

(Signed) ..... *Chairman.*

(Date) .....

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III.]

Examined by the Council ..... *Read at the Ordinary Meeting* ..... *Balloted for* .....

APPENDIX.

[FORM B.]

Mr. ..... of .....

born on the ..... day of ....., being desirous of admission as a Student

of the Society, I recommend him, from personal knowledge, as in every respect worthy of election.

The candidate .....

Here specify fully such facts, with dates, *concerning the education of the candidate as he, or his proposer, may deem necessary to convince the members that the candidate has the proper qualifications for studentship:—*

(*vide* Rule I.)

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On the above grounds I propose him to the Council as a proper person to become a Student of the Society.

(Signed) ..... *member.*

Date .....

We, the undersigned, concur in the above recommendation from personal knowledge, and second the proposal.

.....	.....	members
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

In the event of my being elected a Student of this Society I hereby agree to observe all the Rules and Regulations thereof, and to pay all Subscriptions and other sums which under the said Rules and Regulations shall from time to time become due from me to the Society or to any Officer thereof.

Signature of candidate.....

The Council having considered the above recommendation present.....to be balloted for as a Student of the LIVERPOOL ENGINEERING SOCIETY.

(Signed).....*Chairman.*

(Date).....

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III.]

Examined by the Council.....*Read at the Ordinary Meeting*.....*Balloted for*.....

APPENDIX.

[FORM C.]

We, whose names are hereunto subscribed, submit to the Council of the LIVERPOOL ENGINEERING SOCIETY the propriety of transferring Mr. ..... of .....

born on the ..... day of ....., to the class of Members, because

Here specify distinctly the qualifications of the candidate, according to the spirit of Rule II.

.....

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Witness our hands this ..... day of .....

.....	.....	members.
.....	.....	
.....	.....	
.....	.....	
.....	.....	
.....	.....	

The Council of the LIVERPOOL ENGINEERING SOCIETY, meeting on the..... day of.....,

transfer Mr.....from the class of Associate Members to the class of Members.

(Signed).....*Chairman.*

EXCERPT RULES OF THE SOCIETY.

[Here follow copies of Rules I, II and III].

Examined by the Council.....*Read at the Ordinary Meeting*.....*Balloted for*.....

LIVERPOOL ENGINEERING SOCIETY.

HONORARY MEMBERS.

	DATE OF ELECTION	NAME	ADDRESS
	24th Apl., 1895	Baker, Sir Benjamin, K.C.M.G., LL.D., F.R.S., M.Inst.C.E.	2, Queen Square Place, Westminster
	31st Mar., 1897	Barry, Sir John Wolfe, K.C.B., F.R.S., M. Inst. C.E.	23, Delahay Street, Westminster, London, S.W.
	8th Jan., 1896	Derby, Right Hon. The Earl of, K.G., G.C.B.	Knowsley, near Liverpool
	31st Mar., 1897	Fox, Sir Douglas, M. Inst. C.E.	28, Victoria Street, Westminster, London, S.W.
	24th Apl., 1895	Kelvin, Right Hon. Lord, LL.D., F.R.S.	The Library, The University, Glasgow
3.	8th Nov., 1882	Lodge, Sir Oliver Joseph, D. Sc., F.R.S.	University College, Birmingham
1.	8th Jan., 1896	Preece, Sir W. H., C.B., F.R.S.	Gothic Lodge, Wimbledon, Surrey
	2nd Feb., 1881	Reynolds, Osborne, M.A., F.R.S.,	Owens' College, Manchester
	2nd Mar., 1898	White, Sir William H., K.C.B., LL.D., F.R.S.	Cedarcroft, Putney Heath, London

9 Total Number of Honorary Members.

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

MEMBERS.

DATE OF ELECTION	NAME	ADDRESS
17th Feb., 1897	Adamson, John, Assoc. M. Inst. C.E.	152, Bedford Road, Bootle
2nd Mar., 1898	Aitchison, G. C., Assoc. M. Inst. C.E.	Snowdon Mountain Railway, Llanberis, North Wales
8th Nov., 1893	Alexander, John T.	Building Surveyor's Office, Municipal Buildings, Liverpool
19th Feb.. 1896	Allen, Cecil A., M.I.N.A.	White Star Works, Bootle
19th Feb., 1896	**Allen, Edward,** M. I. Gas E. *Member of Council.*	Gas Office, Duke Street, Liverpool
4th Apl., 1900	Allen, S. Proctor	
13th Dec., 1899	Allott, Charles S., M. Inst. C.E., M.I. Mech. E.,	46, Brown Street, Manchester
13th Dec., 1899	Allott, Henry N., Assoc. M. Inst. C.E.	46, Brown Street, Manchester
26th Nov., 1890	Aman, Frederick T., Assoc. M. Inst. C.E.	City Engineer's Office, Municipal Buildings, Liverpool
2. 7th Nov., 1894	Anderson, J. Wemyss, Assoc. M. Inst. C.E., M. I. Mech. E.	The University, Liverpool
21st Feb., 1900	Armstrong, F. C.	
4th Apl., 1900	Ashmore, Thomas	Westmoreland Foundry, Westmoreland Place, Liverpool
1. 13th Nov., 1895	**Aspinall, John A. F.,** M. Inst. C.E., M. I. Mech. E., M.I. and S. Inst. *Past President*, 1900-1901. (*Life Member.*)	Gledhill, Mossley Hill Drive, Liverpool
22nd Mar., 1899	Atkins, Evan A., A.M.I.Mech. E.,	9, Breckside Park, Anfield, Liverpool
26th Nov., 1890	Baird, Andrew H.	22, Dutton Street, Liverpool
28th Jan., 1903	Baldry, H. O., M. Inst. C. E.	21, Queen Anne's Gate, Westminster, London, S.W.
11th Jan., 1893	Barclay, George	c/o Messrs. J. Glynn & Son, 14, Chapel Street, Liverpool
1. 13th Nov., 1895	Barham, H. G. Foster, Assoc. M. Inst. C.E.	"Marycourt," Bridgewater, Somerset
20th Dec., 1893	Barker, Eric G., M. I. Mech. E.,	Box 96, Government Railway, Freetown, Sierra Leone, W. Africa
1. 18th Nov., 1903	Balfour, George	c/o Messrs. J. G. White & Co., 22a, College Hill, Cannon Street, London, E.C.
7th Nov., 1894	Barnes, J. E. Lloyd, Wh. Sc., M.I. Mech. E.	34, Castle Street, Liverpool
2nd Nov., 1887	Barton, A., Assoc. M. Inst. C.E., A.M.I. Mech. E.	21, Northumberland Avenue, Charing Cross, London, W.C.
19th Nov., 1902	Bates, William, Assoc. M. Inst. C.E.	Deva Cottage, Rose Mount, Oxton

	DATE OF ELECTION	NAME	ADDRESS
	31st Jan., 1894	Bayley, George R.	21, Victoria Road, Waterloo, near Liverpool
	7th Nov., 1894	Beckett, William M., Assoc. M. Inst. C.E.	Temple Chambers, 33, Brazennose Street, Manchester
	29th Nov., 1899	Bell, Allan, A.M.I. Mech. E.	34, Kimberley Street, Liverpool, S.
1.	5th Nov., 1884	Bellamy, C. R., Assoc. M. Inst. C.E.	Corporation Tramways Department, 6, Sir Thomas Street, Liverpool
2.	13th Mar., 1878	**Bevis, R. Ratsey,** M. Inst. C.E., *Past President*—1884.	Birkenhead Iron Works, Birkenhead
	4th Dec., 1901	Bingham, James B.	Electricity Works, Victoria Road, Kirkaldy
	5th Dec., 1900	Bishop, C. Herbert, Assoc. M. Inst. C. E., A.M.I. Mech. E.	89, Hanover Street, Liverpool
	23rd Jan., 1889	Blackburn, R. N., Wh. Sc.	Messrs. Blackburn & Sons, 20, North John Street, Liverpool
1.	11th Dec., 1895	Blair, Malcolm	Messrs. Francis Morton & Co., Garston, Liverpool
1.	19th Oct., 1887	Blair, W. N., M. Inst. C.E.,	Vestry Hall, St. Pancras Road, London, N.W.
	4th Apl., 1900	Blakeley, E. F.	10, Somerville, Poulton Road, Seacombe
	16th Nov., 1904	Bley, Otto A.	28, Ford Street, New Brighton
	25th Feb., 1885	Blood, F. W.	Grafton Saw Mills, Grafton Street, Liverpool
	28th Jan., 1903	Blundell, Harry, M. Inst. C.E.	44, Grosvenor Road, Claughton, Birkenhead
	4th May, 1892	**Boscawen, P. Noel,** Assoc. M. Inst. C.E. *Member of Council.*	Engineer's Office, Dock Yard, Liverpool
1.	26th Mar., 1890	**Boulnois, H. Percy,** M. Inst. C.E., F.S.I. *Past President*—1893-94.	Abbey Cottage, Bisham, Marlow
5.	24th May, 1876	Boult, W. S., Assoc. M. Inst. C.E.,	32, North Side, Wandsworth Common, London, S.W.
	16th Nov., 1898	Bourne, J.	Surveyor, Urban District Council, Rawmarsh, Yorks.
	8th Dec., 1875	Bovey, Henry T., M.A. Cantab., Assoc. M. Inst. C.E.	Professor of Engineering, McGill University, Montreal, Canada
	9th Nov., 1892	Bowden, F. W., Assoc. M. Inst. C.E.,	18, Eastern Drive, Grassendale, Aigburth
	23rd Jan., 1889	Bower, W. Nelson, M. I. Mech. E., Assoc. M. Inst. C.E.	402, Lytham Road, South Shore, Blackpool
	16th Nov., 1904	Brace, George R.	25, Water Street, Liverpool
	16th Nov., 1904	Brady, Charles R., Assoc. M. Inst. C.E.	13, Warren Street, Stockport
1.	27th Sept., 1880	**Bramall, Henry,** M. Inst. C.E. *Past President*—1883.	Pendlebury Collieries, near Manchester
	25th Jan., 1888	**Brew, J. B.** *Member of Council*	17, York Street, Liverpool
6.	19th Nov., 1885	Brightmore, Arthur Wm., D.Sc., M. Inst. C.E.	Egham Hill, Egham, Surrey
	13th Feb., 1878	Brinckman, William, Assoc. M. Inst. C.E.	Dinorwic Quarries, Llanberis, Carnarvon
2.	22nd Oct., 1884	**Brodie, John Alexander,** Wh. Sc., M. Inst. C.E., M. I. Mech. E. *Past President*—1898-99.	City Engineer, Municipal Buildings, Liverpool
	29th Jan., 1902	**Brodie, Robert,** M. Inst. C.E. *Member of Council.*	15, Priory Street, Birkenhead

DATE OF ELECTION	NAME	ADDRESS
1.W. 9th Nov., 1892	**Brodie, William,** Assoc. M. Inst. C.E. *Member of Council*	Engineer's Office, Dock Yard, Liverpool
1.S. 7th Nov., 1894	Brown, David	Canal Ironworks, Hawthorne Rd., Bootle
14th Jan., 1903	Browne, W. D. Shaw	40, Plattsville Road, Wavertree, Liverpool
3rd Apl., 1895	Browne, Wallis V.	36, Orrell Park, Aintree, L'pool
11th Dec., 1895	Brownridge, Charles, M. Inst. C.E.	Borough Surveyor, Town Hall, Birkenhead
18th Mar., 1896	**Bruce, W. J. Willett,** R.N.R. *Member of Council*	White Star Works, Strand Road, Bootle
28th Jan., 1903	Bruce, Wm. T. C.	49, Sefton Street, Liverpool
25th Jan., 1888	Buchanan, J. H., Assoc. M. Inst. C.E., M.I.N.A.	Oswald Chambers, 5, Oswald Street, Glasgow
22nd Jan., 1896	Buckwell, G. W., Wh. Sc., M. I. Mech. E., M.I.N.A., M. I. Mar. E.	Ern Holme, 10, Park Road, Monton Green
21st Nov. 1900	Bullough, C. Oswald	
2nd Mar., 1898	Bunch, Charles E.	Dallam and Bewsey Forges, Warrington
15th Nov., 1899	Burlton, F. J.	Messrs. J. Crosfield & Sons, Warrington
3. 14th Feb., 1883	Burton, G. L., Assoc. M.Inst. C.E.,	Ymuiden, Warren Road, Blundellsands
27th Jan., 1892	Bush, Robert, B.A., M. Inst. C.E.	Engineer's Office, Dock Yard, Liverpool
4th Apl., 1900	Callender, Thomas O., M.I.E.E.,	Hamilton House, Victoria Embankment, London, E.C.
18th Nov., 1803	Callow, Douglas J.	17a South Castle Street. Liverpool
18th Mar., 1896	Calthrop, Everard Richard, M. Inst. C.E., M.I. Mech. E.	3, Crosby Square, Bishopgate Street Within, London, E.C.
15th Jan., 1890	Capstick, R.	74, Grafton Street, Liverpool
4th Apl., 1900	Carr, Isaac, M. Inst. C.E.	Farnworth, Widnes
14th Jan., 1903	Carter, Arthur H.	Public Offices, Litherland
15th Nov., 1899	Carter, Richard	Liverpool Gas Works, Garston
9th Mar., 1887	Carter, William	Hydraulic Eng. Co., Chester
26th Feb., 1890	Cartwright, Joshua, M. Inst. C.E.,	Peel Chambers, Bury, Lancs.
15th Nov., 1899	Catchpole, J. W.	163, Moscow Drive, Stoneycroft, L'pool
27th Nov., 1895	Caulton, Fred.	14, Hemans Street, Liverpool
13th Dec., 1899	Chapman, Alfred, M. Inst. C.E.	Messrs. Fawcett, Preston & Co., York Street, Liverpool
13th Nov., 1895	Clarke, G. Edgar, Assoc. M. Inst. C. E.	Borough Surveyor, Municipal Offices, Boston, Lincolnshire
16th Nov., 1899	Clarke, Herbert G., Assoc. M. Inst. C.E.	City Engineer's Department, Guildhall, Nottingham
11th Nov., 1896	Clarke, John H.	Monkbridge Iron and Steel Works, Leeds
20th Nov., 1901	Cliff, Thomas P. B.	The Admiralty, 21, Northumberland Avenue, London, W.C.
4th Dec., 1901	Clothier, T. Dawson	Electric Light and Power Station, Pine Grove, Bootle
10th Jan., 1900	Clough, Alfred, Assoc. M. Inst. C.E.	14, Mersey Avenue, Aigburth, Liverpool
13th Nov., 1895	Collard, Alfred S.	Messrs. R. P. Houston & Co., Dale Street, Liverpool
11th Nov., 1896	Collard, J. A., M.I.N.A.	61, Drury Buildings, 21, Water St.

	DATE OF ELECTION	NAME	ADDRESS
1.	21st Nov., 1883	Collier, H. M. H., Assoc. M. Inst. C.E.	North Eastern Railway, Engineer's Office, New Dock Works, Middlesbrough
	21st Mar., 1900	Collins, Brierley H., M.I.E.E.	17, Hawarden Avenue, Sefton Park, Liverpool
1.	7th May, 1890	Collis, W. H., Assoc. M. Inst. C.E.,	7, Barn Hill Road, Wavertree
	12th Jan., 1887	Comerford, Edward, A. M.I. Mech. E.	Abbot's Grange, Liverpool Road, Chester
	11th Jan., 1905	Conner, James	c/o Messrs. Dick, Kerr & Co., Preston
	6th Apl., 1887	Cook, E.	18, Esplanade, Waterloo
1.	12th Jan., 1887	**Cooper, Francis E.,** Assoc. M. Inst. C.E. *Member of Council.*	City Engineer's Department, Municipal Buildings, Liverpool
1.	4th Apl., 1894	Corbett, Joseph, M.S.I.	Borough Engineer, Town Hall, Salford
2.	10th Oct., 1877	Cornish, E. S.	
	26th Mar., 1902	Corrie, H. W.	Surveyor, Urban District Council Offices, Lower Bebington, Cheshire
	5th Dec. 1900	Cottle, Frank	Borough Surveyor's Office, Douglas, Isle of Man
1.	26th Feb., 1890	**Cottrell, S. B.,** M. Inst. C.E., M.I. Mech. E. *Past President*—1896-97.	L'pool Overhead Railway, Pacific Buildings, 31, James Street
	9th Apl., 1902	Coulston, Percy B.	c/o The Brush Electrical Engineering Co., Limited, Haworth's Building, Cross Street, Manchester
	16th Dec., 1903	Crawford, R. S.	58, Kenmare Road, Sefton Park, Liverpool
	5th Feb., 1896	Crichton, Charles	Huskisson Engine Works, L'pool
	8th Feb., 1905	Croker, S. H.	119, Penny Lane, Sefton Park, Liverpool
	1st April, 1896	Crouch, John P., Assoc. M. Inst. C.E.	Locomotive Works, L. & Y. Ry., Horwich, Lancashire
1.	16th Nov,, 1898	Crump, Arthur H., M.I.M.E.	21, Dale Street, Liverpool
1.S.	20th Feb., 1895	Cunningham, Brysson, B.E., Assoc. M. Inst. C.E.	8, Walmer Road, Waterloo, near Liverpool
	17th Nov., 1897	Daglish, Harry B., M. I. Mech. E.,	Messrs. Robert Daglish & Co., St. Helens
5.	16th Mar., 1881	**Darbishire, Charles Henry,** J.P., Assoc. M. Inst. C.E. *Past President*—1888. *(Life Member.)*	Penmaenmawr, North Wales
	11th Jan., 1893	Darby, Jas. T.	Church Street West, Bootle
1. S.	17th Nov., 1897	Davidson, J. R., M. Sc., Assoc. M. Inst. C.E.	6, Ivanhoe Road, Sefton Park, Liverpool
	9th Nov., 1892	Davies, Fred. Wm., A.M.I. Mech. E.	Water Engineer, St. Peter's Churchside, Nottingham
	30th Nov., 1904	Davies, R. Hoskins	7, Milton Road, Fairfield
	20th Feb., 1889	Davies, T.	Widnes Iron Works, Widnes
	11th Nov., 1896	Davies, T. W., Assoc. M. Inst. C.E., F.G.S.	41, Park Place, Cardiff
	18th Dec., 1901	Davis, Frank	Superintendent Engineer, County Asylum, Littlemore, Oxford
	20th Nov., 1901	Daw, Hilder, M.R.I., A.I.N.A.	Rydal Mount, Cheadle Heath, Stockport
1.	25th Apl., 1877	Deacon, George F., LL.D., M. Inst. C.E., M. I. Mech. E.	Gt. George Street Chambers, 16, Gt. George St., Westminster, S.W.

	DATE OF ELECTION	NAME	ADDRESS
1.	15th Nov., 1899	Deakin, G. Welsby, Assoc. M. Inst. C.E., A.M.I. Mech. E.	"Clovelly," Church Road, Penn Fields, Wolverhampton
	28th Mar., 1877	Dickson, John, Assoc. M. Inst. C.E.,	Glaisdale Ironworks, Grosmont, Yorks.
	12th Nov., 1890	Douglas, James T.	Queen B'dgs, 11, Dale St., Liverpool
	7th Feb., 1900	Downe, Reginald S.	Town Hall, Southport
	13th Nov., 1895	Downie, Thomas	19, Oldhall Street, Liverpool
	8th Feb., 1893	Duff, Peter	18, Radnor Place, Birkenhead
5. W.	13th Feb., 1878	**Duncanson, Thomas,** M. Inst. C.E. *Vice-President.*	16, Deane Road, Liverpool
	16th Nov., 1904	Dutton, George H.	17, Priory Street, Birkenhead
	25th Apl., 1900	Edge, Fred J., M. Inst. C.E.	City Engineer, Town Hall, Newcastle-on-Tyne
	27th Jan., 1886	Edmiston, J. B., M. I. Mech. E., M.I.N.A.	B17, Exchange Buildings, Rumford Street, Liverpool
2.	25th Sept., 1878	Ellington, Edward B., M. Inst. C.E.,	Palace Chambers, 9, Bridge Street, Westminster, London, S.W.
1.	25th Feb., 1903	Ellis, Somers H., Assoc. M. Inst. C. E.	17, Priory Street, Birkenhead
	11th Nov., 1896	Ellis, Edward, M. Inst. C.E.	Great Northern Railway, Leeds
1.	14th Jan., 1903	Ellison, A. R.	Hoscote, West Kirby
	28th Jan., 1903	Farrington, T. B.	Trinity Square, Llandudno
	11th Mar., 1885	Ferber, E. G., M. I. N.A.	City of Dublin Steam Packet Co., 9, Regent Road, Liverpool
	22nd Apl., 1896	Fernie, James	30, Brunswick Street, Liverpool
	10th Jan., 1900	Ferranti, S. Z. de, M. Inst. C.E., M.I.E.E.	31, Lyndhurst Road, Hampstead, London, N.W.
	11th Feb., 1880	Fitz-Gibbon, Gerald, M. Inst. C.E.	Aire & Calder Navigation, Leeds
	10th Oct., 1886	Fosbery, A. C. W.	Assistant Engineer, Bombay Port Trust, Bombay
	16th Nov., 1898	Fosbery, Charles Leslie	Harbour Works, Colombo, Ceylon
	8th Feb., 1905	Foster, Llewellyn, Assoc. M. Inst. C.E., M.I.E.E.	c/o Michael Longridge, 12, King Street, Manchester
	27th Jan., 1904	Fowke, T. M.	L. & N. W. Ry., Edge Hill, Liverpool
3.	13th Apl., 1898	**Fowler, A. F.,** M. Inst. C.E., M.I. Mech. E. *Vice-President.*	3, Cook Street, Liverpool
	5th Dec., 1894	Fozzard, William C.	87, Walton Breck Road, L'pool
	21st Nov., 1894	Fraser, Robert B.	Messrs. A. & R. Brown & Co., 90, Regent Road, Liverpool
	16th Apl., 1902	Gaskell, Holbrook, A.M.I. Mech. E.	"Erindale," Frodsham, Cheshire
	25th Nov., 1896	Gaskin, Fredk. Wm., Assoc. M. Inst. C.E.	Cotebrook Reservoir, Tarporley, Cheshire
	8th Feb., 1893	Geddes, Chris., M. I. Mech. E.	2A, Drury Lane, Water Street, Liverpool
	10th Feb., 1904	Gibbons, J. M.	18, Bidston Road, Oxton
	8th Feb., 1905	Gibson, Ralph E., Assoc. M. Inst. C.E.	1, Waverley Road, Sefton Park, Liverpool
	15th Nov., 1899	Given Ernest C., Assoc. M. Inst. C.E., A. M.I. Mech. E.	4, Hargreaves Road, Liverpool
1.	7th Nov., 1894	Glover, James, M.A., M. Inst. C.E.	Lowton House, Lowton, Lancs.

	DATE OF ELECTION	NAME	ADDRESS
3.	6th Oct., 1880	Goldstraw, William	Building Surveyor, Municipal Buildings, Liverpool
	21st Nov., 1900	Goodacre, W. Geoffrey, A.M.I. Mech. E.	27, Moreton Avenue, Stretford, Manchester
	12th Nov., 1890	Goodwin, Gilbert S., M.I.N.A.	Alexandra Buildings, 19, James Street, Liverpool
	1st Dec., 1897	Grant, Allan J.	Holly Lodge, Formby, Lancashire
	27th Jan., 1904	Gray, W. Turnbull	38, South Castle Street, Liverpool
	4th Apl., 1900	Grayson, H. M., M.I.N.A.	20, Water Street, Liverpool
	7th May, 1890	Greaves, R. M.	Wern, Tremadoc R.S.O., N. Wales
	19th Nov., 1902	Greenhough, James	"Marshville," 53, Derby Road, Farnworth, Near Widnes
	6th Apl., 1892	Griffith, T. H.	10, Bedford Place, London, W.C.
	16th Nov., 1904	Griffiths, John A., M.I.N.A.	Clovelly, Waterloo Park, near Liverpool
	11th Jan., 1905	Griffiths, Ernest,	51, North John Street, Liverpool
1.	16th Nov., 1904	Grundy, J., M.I.N.A.	23, St. Alban's Road, Bootle
	9th Nov., 1892	Haarer, Ernest C., M.I. Mech. E.	Hydraulic Engineering Co., Ltd., African Chambers, Old Hall Street, Liverpool
	12th Nov., 1890	Hall, Watkin, Assoc. M. Inst. C.E.	Surveyor, District Council Offices, Great Crosby, near Liverpool
	31st Mar., 1897	Hallas, George H.	Huyton, near Liverpool
1.W.	18th Mar., 1891	Hamilton, Andrew, M.I.N.A.	c/o Messrs. G. S. Goodwin & Co., 19, James Street, Liverpool
	9th Mar., 1887	Hardaker, A. E.	Engineer's Office, L. & Y. Ry., Hunt's Bank, Manchester
	11th Jan., 1905	Harris-Burland, W. M.	27, Leopold Road, Blundellsands, near Liverpool
	9th Mar., 1892	Harvey, Robert F., Assoc. M. Inst. C.E.	16, Seaton Buildings, 17, Water Street, Liverpool
1.S.	25th Nov., 1891	Haswell, Frederick J., M. I. Mech. E.	The Hull Hydraulic Power Co., Machell Street, Hull
	25th Apl., 1900	Hawkins, Elyot S., A.M.I. Mech. E.	General Manager, Colne Valley Ry., Halstead, Essex
	9th May, 1888	Hay, Arthur C., M.I.N.A.	23a, Exchange Buildings, Liverpool
5.	28th Oct., 1885	**Hele-Shaw, H. S.,** LL.D., Wh. Sc., F.R.S., M. Inst. C.E., M.I. Mech. E., F. R. Met. Soc. *Past President*—1894-95. (*Life Member.*)	South African Technical Institute, Johannesberg, S.A.
	13th Nov., 1895	Helliwell, Robt. B.	13, Hougomont Avenue, Waterloo
1.	5th Dec., 1900	Hidden, E. J.	F24, Exchange Buildings, L'pool
	15th Nov., 1899	Hide, W. J.	28, Hawarden Avenue, Sefton Park, Liverpool
	18th Nov., 1903	Hirst, John A.	Northgate Electrical Works, Chester
	30th Jan., 1901	Hobson, Walter D., Assoc. M. Inst. C.E.	Nantlle, Penygroes, R.S.O.
	19th Dec., 1900	Holland, Albert	Doonagore, via Lehinck, Co. Clare, Ireland
	19th Nov., 1902	Holliday, Edward	179, Warbreck Moor, Aintree
	9th Nov., 1892	Holliday, J. N. T.	Water Engineer's Department, Municipal Buildings, Liverpool
	13th Jan., 1904	Hollingsworth, E. M., A.M.I. Mech. E., A.M.I.E.E.	Grosvenor Road, St. Helens
	13th Nov., 1895	Holme, Arthur H., J.P., Assoc. Inst. C.E.	6, Gambier Terrace, Liverpool

	DATE OF ELECTION	NAME	ADDRESS
4.	8th Nov., 1882	**Holmes, Arthur Bromley,** M. Inst. C.E., M.I.E.E. *Past President.*—1899-1900.	36, Princes Avenue, Liverpool
3.	25th Apl., 1877	**Holt, Alfred,** M. Inst. C.E. *Past President*—1881.	1, India Buildings, Water Street, Liverpool
	13th Mar., 1901	Holt, Charles F.	70, Drury Buildings, Water Street, Liverpool
	3rd Feb., 1897	Honiball, Charles R., M. I. Mech. E., M.I.H.V.E.	121, Great Mersey Street, Liverpool
1.D.	13th Nov., 1895	**Hope, Alaric,** Assoc. M. Inst. C.E., A. M. I. Mech. E. *Hon. Librarian.* (*Life Member.*)	Engineer's Office, Dock Yard, Liverpool
	14th Nov., 1888	Hope, W., J.P., Assoc. Inst. C.E.	10, Blackstock Street, Liverpool
	13th Nov., 1895	Horner, Joseph W.	11, Stuart Street, Narborough Road, Leicester
	4th Apl., 1900	Horsburgh, S. Gordon	16, College Avenue, Great Crosby, near Liverpool
	15th Nov., 1899	Horsfall, W. M.	22, Hackins Hey, Liverpool
	27th Jan., 1904	Howarth, J. W.	55, Victoria Crescent, Eccles
1.	12th Feb., 1890	Howells, D. J.	c/o Engineering & Foundry Co., Ltd., Bellino-Fenderick, Odessa, Russia
1.	10th Oct., 1877	**Hudleston, Ferdinand,** M. Inst. C.E. *Past President*—1890-91.	25, Victoria Street, Westminster, London, S.W.
	14th Dec., 1904	Hughes, George, M. Inst. C.E.	Chief Mechanical Engineer, Lanc. and Yorks. Ry., Horwich, near Bolton
	3rd Nov., 1886	Hulme, E., Assoc. M. Inst. C.E.	51, North John Street, Liverpool
1.D.	18th Nov., 1903	Hunt, Louis J., Assoc. M. Inst. C.E., A.M.I.E.E.	c/o Sandycroft Foundry Co., Ltd., Chester
	30th Nov., 1904	Hunter, Thomas B.	Wirral Railway, Docks Station, Birkenhead
1.	13th Jan., 1886	Hurtzig, A. C., M. Inst. C.E.	2, Queen Square Place, Queen Anne's Mansions, Westminster, S.W.
	8th Mar., 1905	Hyde, George	Parkholme, St. Helens, Lanc.
	18th Dec., 1901	Isaac, B. Richard	45, South John Street, Liverpool
	1st May, 1889	Johnson, Joshua	1, Brompton Avenue, Sefton Park
	7th Nov., 1894	Johnson, W. B.	4, Clayton Square, Liverpool
	20th Feb., 1889	**Johnston, R. E.,** M. Inst. C.E. *Past President*—1892-93. (*Life Member.*)	Engineer's Office, Woodside Railway Station, Birkenhead
	15th Jan., 1902	Johnston, Robert W.	Borough Engineer's Department, Town Hall, Birkenhead
	30th Jan., 1901	Jones, A. Dansey, A.M.I. Mech. E.	L. & Y. Ry., Locomotive Department, Horwich, near Bolton
	13th Nov., 1895	Jones, Charles	14, Cranhurst Road, N., Mirden Green, London, N.W.
	15th Jan., 1902	Jones, Cosmo R.	Water Works Department, 109, Long Street, Cape Town
	26th Feb., 1890	Jones, I. M., M. Inst. C.E.	City Surveyor, Town Hall, Chester
	30th Nov., 1904	Jones, Stanley P.	26, Neville Road, Waterloo, near Liverpool
	12th Dec., 1888	Jones, William	170, Walton Village, Walton
	22nd Oct., 1879	Jones, W. H., Assoc. M.Inst.C.E.,	Engineer's Office, Dock Yard, Liverpool
	24th Feb., 1904	Jones, W. P.	5, Springvalley Gardens, Morningside, Edinburgh
	24th Apl., 1895	Keay, R. D.	3, Lee Park, Blackheath, London, S.E.

	DATE OF ELECTION	NAME	ADDRESS
	23rd Dec., 1891	Kelly, Archie	Elsinore, Promenade, Liscard
	10th Feb., 1904	Kemp, J. Pattison	Central Station, Mersey Railway, Birkenhead
	7th Nov., 1894	Kendall, Frank A.	
1. D.	10th Apl., 1902	Kenyon, George Cecil, M. Inst, C.E., A.M.I. Mech. E., Assoc. M. Am. Soc. C.E.	"Beaucoin," Aughton, near Liverpool
	29th Apl., 1903	Kenyon, Francis, Assoc. M. Inst. C. E.	Contractor's Office, Wolton-under-Wood, near Aylesbury
1.	16th Nov., 1898	Ker, W. Arthur, Assoc. M. Inst. C.E.	c/o Messrs. Paterson, Cooper & Co., Ltd., Patella Works, Paisley, N.B.
1.	13th Jan., 1904	Kershaw, J. B. C., F.I.C., F.S.S.	West Lancashire Laboratory, Waterloo
	16th Jan., 1878	King, William, M. Inst. C.E.	5, Beach Lawn, Waterloo, nr. L'pool
	3rd Nov., 1886	Kinghorn, J. G., M.I.N.A.	Tower Buildings, Water Street, Liverpool
	21st Feb., 1900	Kirkland, George B.	Vauxhall Foundry, Banastre Street, Liverpool
	18th Nov,, 1903	Kirkpatrick, W. D., A.M.I.E.E.,	Lincluden. Penkett Road, Liscard
	16th Apl., 1902	Knight, Henry Kirk	Sleaford, Lincolnshire
	16th Nov., 1904	Knollys, R. W.	Dock Yard, Liverpool
	20th Jan., 1897	Knowles, Thomas R.	Old Park Terrace, Wednesbury
	9th Jan., 1887	Legg, W. A., M. Inst. C.E.	c/o Thos. Stewart, M. Inst. C.E., 6, St. George's Chambers, Cape Town
	31st Mar., 1897	Le Mesurier, Wm. Henry, M. Inst. C.E.	Dock Yard, Liverpool
	10th Feb., 1904	Le Tall, F. W.	c/o Messrs. British Insulated and Helsby Cables, Ltd., Prescot
	20th Jan., 1897	Lewis, Thomas	65, Hornby Road, Bootle
	21st Mar., 1900	Liardet, W. H.	10, Gambier Terrace, Liverpool
	15th Nov., 1899	Lipscomb, H. N.	Locomotive Department, Midland Railway, Liverpool
	14th Jan., 1903	Lind, Andrew L., A.I.E.E.	5, Cecil Road, Prenton, Birkenhead
	10th Jan., 1900	Lister, A. Hamilton	Hill Foot, Breeze Hill, Bootle
	27th Feb., 1901	Lynn, J. R. Dent	1, Stuart Road, Waterloo, near Liverpool
3.	7th June, 1876	Lyster, Anthony George, M. Inst. C.E.	Engineer-in-Chief, Dock Yard, Liverpool
	21st Nov., 1900	Macaulay, John, A.M.I. Mech. E.	Public Health Dept., Municipal Buildings, Liverpool
	13th Nov., 1895	Mackenzie, James, M.I.N.A.	c/o Messrs. David Rollo & Sons, Fulton Engine Works, L'pool, N.
1. W.	22nd Nov., 1893	Macmuldrow, W. G. P.	P. O. Box 379, Cape Town, S. A.
	24th Feb.. 1904	Macnab, J. F.	127, Crosby Road, Seaforth
6.	25th Apl., 1877	**Maginnis, Arthur J.,** M. Inst. C.E., M.I.N.A., M.I.M.E. *Past President*—1895-96.	28, Chapel Street, Liverpool
1.	18th Nov., 1903	**Marchant, Professor E. W.,** D.Sc., A.M.I.E.E. *Member of Council.*	The University, Liverpool
	4th Apl., 1900	Marples, Ernest	"Kograh," Minstead Road, Gravelly Hill, Birmingham
	24th Jan., 1900	Marr, John J.	18, Moorfields, Liverpool
	16th Nov., 1898	Marsden, George Ellis	"Heyfield," Little Sutton, Cheshire
	4th Nov., 1885	Mason, Charles	75, Gwendoline Street, Liverpool

	DATE OF ELECTION	NAME	ADDRESS
	2nd Dec., 1903	Maxwell, Lyon H.	c/o Messrs. Bruce & Still, Limited, 49, Sefton Street
	16th Nov., 1898	McCulloch, A.	
	16th Dec,, 1903	McHaffie, H.G.	27, Church Road, Hoylake
	2nd Dec., 1903	McLeod, R. S.	21, Victoria Avenue, Didsbury, Manchester
1.S.	18th Nov., 1903	Meyer, H. S., M.I.E.E.	c/o British Thomson-Houston Co., Rugby
	22nd Mar., 1893	Millar, Thomas	c/o Messrs. Gourlay Bros. & Co., Dundee
	8th Nov., 1893	Miller, Henry	Council Offices, Heysham, Lancashire
3. D.	8th Nov., 1882	**Miller, Thomas L.**, M.Inst. C.E., M.I. Mech. E., M.I.E.E. *Past President*—1903-04.	7, Tower Buildings N., Water Street, Liverpool
	8th Nov., 1893	Mills, Frank, Assoc. M. Inst. C.E., M. I. Mech. E. (*Life Member.*)	District Railway Engineer, Kuala Lumpur, Selangor, Malay Peninsula, Federated Malay States
4.	9th Apl., 1879	**Mills, William E.**, F.S.I., *Past President*—1885. *Member of Council.*	57, Hamilton Square, Birkenhead
	4th Dec., 1901	Minns, R. J.	10, Gardner Rd., Tue Brook, L'pool
	11th Jan., 1905	Moger, C. H.	c/o Messrs. Grayson, Ltd., Birkenhead
1.	1st Dec., 1897	Molyneux, Thomas	City Engineer's Office, Municipal Buildings, Liverpool
	27th Jan., 1904	Monkhouse, F. L.	The Well Fire Co., Paradise Street, Liverpool
1.	7th Nov., 1894	Morison, D. B., M.I. Mech. E., M.I.N.A.	Messrs. T. Richardson & Sons, Engine Works, Hartlepool
	16th Nov., 1898	Moulding, Thos., Assoc. M. Inst. C.E.	City Surveyor's Office, Exeter
	4th Dec., 1901	Muckley, W. H., Wh. Sc., M.I. Mech. E.	Corporation Tramways, Lambeth Road, Liverpool
	21st Mar., 1900	Muir, John R. M.	Messrs. H. & C. Grayson, Ltd., 179, Regent Road, Liverpool
	21st Mar., 1900	Muir, William	Liverpool Fire Salvage Association, 16, Hatton Garden, Liverpool
2.	16th Oct., 1889	**Musker, Arthur,** M. Inst. C.E., M. I. Mech. E. *Past President*—1901-02.	Simms Road, Tuebrook, Liverpool
	11th Nov., 1896	Musker, Charles, Assoc. M. Inst. C.E.	Simms Road, Tuebrook, Liverpool
	10th Jan., 1900	Naftel, Percy H.	18, Earlston Road, Egremont, Ches.
	10th Feb., 1904	Nash, R. P.	Prescot and District Electric Supply Station, Prescot, Lancs.
	14th Dec., 1904	Neachell, Ed. John	Overhead Railway, 31, James Street, Liverpool
	11th Nov., 1896	Neville, John U.	7, James Street, Liverpool
	13th Nov., 1895	Newall, James	Messrs. J. Crosfield & Son, Warrington
	22nd Nov., 1882	Newell, Thos. M., M. Inst. C.E.	Engineer, North Eastern Railway Company, Dock Office, Hull
	16th Nov., 1904	Nichols, C. B., M.I.N.A.,	23, Euston Grove, Birkenhead
1.	11th Nov., 1896	Nicholson, James N., Assoc. M. Inst. C.E.	c/o Messrs. Wood & Fowler, 3, Cook Street, Liverpool
1.	27th Jan., 1904	Norris, Wm., Assoc. M. Inst. C.E., M.I. Mech. E.	Lancashire Steam Motor Co., Leyland, Lancs.

	DATE OF ELECTION	NAME	ADDRESS
	16th Nov., 1904	O'Brien, H. E., B.Sc., Assoc. M. Inst. C.E., A.M.I.E.E.	Andrew's Lane, Formby, near Liverpool
	9th Apl., 1902	O'Hanlon, James	Messrs. Crossley Bros., Limited, Brunswick Street, Liverpool
	14th Apl., 1897	Oglethorpe, W. A., M.I.N.A.	Engineer's Office, Dock Yard, Liverpool
	19th Nov., 1902	Owens, Harold	City Engineer's Department, Municipal Buildings, Liverpool
	4th Apl., 1900	Page James B.	A19, Exchange Buildings, Liverpool
1.	5th Dec., 1877	**Pain, Coard S.**, Assoc. Inst. C.E., F.S.I. *Past President*—1886.	14, North John Street, Liverpool *Hon. Treasurer.*
2.	4th Apl., 1894	Parkin, John H., Assoc. M. Inst. C.E.	Corporation Waterworks, Gorpley Reservoir, Todmorden
	11th Mar., 1903	Parkinson, William Whiteside	Corporation Electricity Works, Blackpool
	16th Nov., 1904	Parry, Walter, M. Inst. C.E.	Municipal Engineer, Cawnpore, India
	25th Apl., 1900	Paterson, T. O., M. Inst. C.E.	26, Grosvenor Road, Claughton, Birkenhead
	30th Jan., 1901	Pickering, W. D.	Brunswick Foundry and Engine Works, 41, Sefton St., L'pool
1.	28th Feb., 1877	Pilkington, O. S., Assoc. M. Inst. C.E. *Life Member.*	Ivanhoe, Fferm Bach Road, Craig-y-Don, Llandudno
	13th Nov., 1895	Pilling, S. W.	Welton Hall, Brough, East Yorkshire
	9th Nov., 1892	Platt, S. S., M. Inst. C.E.	Borough Surveyor, Rochdale
	4th Apl., 1900	Pocklington, Fred. A.	
1.	9th Mar., 1887	Pooley, Henry, Jun.	Albion Foundry, Harecastle Junction, Stoke-on-Trent
	2nd Mar., 1898	Pooley, J. S.	69, McAlpine Street, Glasgow
3.	28th Feb., 1877	Potts, John J., Assoc. M. Inst. C.E.,	43, Belmont Street, Southport
	16th Mar., 1881	Price, Joseph, Assoc. M. Inst. C.E., M. I. and S. Inst.	125, Bunhill Row, London, E.C.
1.	1st Dec., 1886	**Priest, Frank E.**, M. Inst. C.E. *Past President*—1904-05.	13, Harrington Street, Liverpool
2.S.	3rd Mar., 1897	Pritchard, P. M., Assoc. M. Inst. C.E., Assoc. M. Am. Soc. C.E.	23, Rutland Avenue, Ullet Road, Liverpool, S.
	4th Apl., 1900	Ransome, G. F.	67, Tithebarn Street, Liverpool
	20th Oct., 1886	Rathbone, A. L., Assoc. M. Inst. C.E. (*Life Member.*)	Greenbank, Liverpool
	16th Jan., 1901	Rathmell, Bernard	16, Parkfield Drive, Liscard
1.D.	1st Dec., 1897	Reade, M. Treleavan	2, South John Street, Liverpool
	6th Dec., 1893	Reeves, Wilfred	"Craigairne," Donegal Park, Antrim Road, Belfast
	23rd Jan., 1889	Richardson, R.	82, Devonshire Road, Liverpool
	12th Feb., 1902	Ridge, Thomas	Bank Chambers, Oswestry
	15th Jan., 1902	Rhodes, Ernest H.	Hazel Brae, Market St., Hoylake
	21st Nov., 1900	Roberts, Cecil H.	25, Hagley Road, Edgbaston, Birmingham
	20th Nov., 1901	Roberts, H. J., M.I. Mech. E.	42, Castle Street, Liverpool
	6th Apl., 1892	Roberts, R. O. Wynne, M. Inst. C.E., F.R. San. Inst.	Water Engineer, Cape Town, S.A.
	19th Nov., 1902	Roberts, Walter S.	Railway Signal Co., Fazakerley

	DATE OF ELECTION	NAME	ADDRESS
	24th Jan., 1900	Robinson, Alex. H., A.M.I.E.E.	Hawthorne House, Oak Hill Park, Liverpool
	7th Nov., 1894	Robinson, J. P.	Springfield Iron Works, Salford, Manchester
	24th Feb., 1904	Rosenheim, E. A., B. Sc. A.M.I.E.E.	1. Croxteth Road, Liverpool
5.	21st June, 1876	**Ross, Alexander,** M. Inst. C.E. *Past President*—1880.	Engineer's Office, Great Northern Railway, King's Cross, London
	11th Feb., 1903	Ross, M. Glen.	27, Handfield Road, Waterloo, near Liverpool
	12th Nov., 1890	Rowlandson, C. A., M.Inst.C.E.	Great Central Railway, M'chester
	13th Nov., 1889	Royston, Ernest R.	15, Water Street, Liverpool
	27th Sept., 1880	Rubery, John T.	Victoria Ironworks, Darlaston, Staffordshire
	9th Nov., 1892	Russell, H. F.	Vine House, Neston, Cheshire
	7th Nov., 1894	Rutherford, A., M.I.N.A.	Neptune Works, Bridge Street, Birkenhead
	21st Feb., 1900	Rutherford, W.	
	19th Nov., 1902	Salter, J. R.	9, North John Street, Liverpool
	25th Sept., 1878 / 17th Nov., 1897	**Salmon, Frank B.,** M. I. and S. Inst. *Past President*—1882.	African Chambers, Oldhall Street, Liverpool
	17th Nov., 1897	Salmon, Harry	Stranton Works, West Hartlepool
2.	3rd Nov., 1886	Saner, J. A.	Weaver Navigation, Northwich
	9th Mar., 1892	Saunders, S. H.	14, Woodland Road, Dacre Hill, Rock Ferry
	21st Feb., 1900	Schultz, Charles S.	
1.	13th Nov., 1895	Scott, Wm. G., M. Inst. C.E.	26, Dingle Lane, Liverpool
	10th Jan., 1900	Sharp, John, M.I. Mech. E., M.I. & S. Inst.	Bolton Iron and Steel Company, Limited, Bolton
	15th Jan., 1890	Sharrock, C. W.	Dorincourt, Grays, Essex
	19th Nov., 1902	Shaw, Joshua	Engineer's Office, Mersey Railway, Central Station, Birkenhead
	12th Mar., 1884	Shawcross, H. J., B.E. (Queen's Univ., Ireland)	Water Engineer's Department, Municipal Buildings, Liverpool
	25th Apl., 1900	Sherley-Price, E. A.	46, Watling Street, London, E.C.
	13th Dec., 1899	Shield, Henry, M. Inst. C.E.	Messrs. Fawcett, Preston & Co., York Street, Liverpool
	28th Mar., 1883	Sinclair, John S., Assoc. M. Inst.C.E.	Surveyor's Office, Town Hall, Widnes
	7th Nov., 1894	Sloan, Robert A., Wh. Sc., M.I. Mech. E.	34, Castle Street, Liverpool
	21st Mar., 1900	Smith, A. G.	42, Falkland Road, Egremont, Cheshire
2.	25th Jan., 1888	**Smith, J. Reney,** M.I. Mech. E., M.I.N.A. *President.*	Messrs. H. & C. Grayson, Ltd., 179, Regent Road, Liverpool
	13th Jan., 1904	Snoxall, G. E., M.I. Mech. E.	16, Merton Grove, Bootle
8.	10th Nov., 1875	Squire, W. W., M. Inst. C.E.	Bristol Docks, Engineer's Office, Cumberland Basin, Bristol
	4th Nov., 1885	Stead, Edward J.	Assistant District Engineer, Public Works Department, Durban, Natal, South Africa
	4th Dec., 1901	Stead, Wm.	Hey House, Preston Avenue, Eccles
2.	20th Nov., 1901	Steele, F. W.	c/o Messrs. C. & A. Musker, Ltd., Simms Rd., Tue Brook, L'pool.

	DATE OF ELECTION	NAME	ADDRESS
	12th Jan., 1887	Stephenson, E. P., Assoc. M. Inst. C.E.	Surveyor's Office, District Council Offices, Llandudno
	18th Nov., 1903	Stevenson, C. Maxwell	Howarth's Buildings, Cross Street, Manchester
	6th Mar., 1895	Stott, Thomas B. *Life Member.*	Woodseat, Eastham, Cheshire
	13th Apl., 1898	Strongitharm, H. H.	14, Cook Street, Liverpool
1.	23rd Nov., 1892	Sutcliffe, Fielden	York Lodge, Crosby Road South, Seaforth
1.	26th Feb., 1890	Taylor, A. Lester, M.I.E.E.	1, Fowell Road, New Brighton, Cheshire
	13th Dec., 1899	Taylor, E. Sydney	Sandycroft Foundry, Hawarden, Flintshire
	7th Mar., 1900	Taylor, James, M.I.E.E.	Heathercliffe, Helsby, Near Warrington
1.	4th Apl., 1900	Taylor, J. R., B.A. (Cantab.), Assoc. M. Inst. C.E.	11, Vincent Square, Westminster, London, S.W.
	12th Mar., 1902	Taylor, Ralph Pierce	The General Supply & Construction Co., 8/10, Bridge St., New York
	25th Mar., 1903	Tennant, James	16, Station Road, Prescot
	26th Oct., 1892	Terry, Stephen H., M. Inst. C.E., M.I. Mech. E.	17, Victoria Street, Westminster, London, S.W.
	9th Mar., 1904	Thomas, Eustace, B.Sc.	c/o Bertram Thomas, Worsley Street, Hulme, Manchester
	7th Mar., 1900	Thompson, F. G.	H. & C. Grayson, Ltd., Regent Road, Liverpool
	30th Nov., 1898	Thomson, G. Carruthers	53, Bedford Road, Rock Ferry
	13th Feb., 1901	Thornton, S. E., Assoc. M. Inst. C.E.	Sanctuary House, Tothill Street, Westminster, London, S.W.
	8th Mar., 1893	Tickle, John J.	Claughton Chambers, Hardshaw Street, St. Helens
	7th May, 1890	Timmins, Arthur, Assoc. M. Inst. C.E.	Argyll Lodge, Runcorn
	19th Nov., 1902	Tiplady, C. E.	Gold Coast Government Ry., Asst. Engineer's Office, Dunkua, W.C.A.
	20th Nov., 1901	Tod, P.	c/o Messrs. E. H. Williamson & Co., Lightbody Street, L'pool
	22nd Jan., 1896	Travers, W. H.	12, Ennerdale Road, New Brighton
4.	25th Apl., 1877	Tudsbery, J. H. T., D. Sc., M. Inst. C.E.	Institution of Civil Engineers, 25, Great George Street, Westminster, London, S.W.
	26th Feb., 1902	Tunstall, Jas. W.	School House, Caledonia St., L'pool
	24th Jan., 1900	Turton, F. T.	Deputy Surveyor, Municipal Buildings, Liverpool
	11th Dec., 1895	Urquhart, R. J., A.M.I. Mech. E.,	Central Chambers, South Castle Street, Liverpool
	5th Nov., 1902	Varley, Geo. P.	Waterloo Foundry, St. Helens, Lancashire
	16th Nov., 1904	Vernon, T. Thornycroft	Atlantic Buildings, Brunswick Street, Liverpool
	25th Jan., 1899	Vicars, Thomas	The Knoll, Newton-le-Willows, Lancashire
	19th Nov., 1902	Vickers, Arthur	6, Hooton Road, Aintree, near Liverpool
	20th Oct., 1886	Vickess, Samuel, Jun.	
1.	26th Feb., 1890	Von Sobbe, F. A., Assoc. M. Inst. C.E.	3, Belvidere Road, Liverpool

	DATE OF ELECTION	NAME	ADDRESS
	26th Apl., 1899	Wade, J. Arthur	27, Kremlin Drive, Stoneycroft, Liverpool
	27th Jan., 1886	Wakem, Peter H.	6, Prescot Drive, Newsham Park, Liverpool
	27th Jan., 1904	Wallace, W. G.	c/o British Thomson-Houston Co., Manchester
1.	3rd Nov., 1886	Ward, E. T., Assoc. M. Inst. C.E.,	Hillside, Beech Road, Northwich
	25th Nov., 1896	Watson, R. W.	30, Devonshire Road, Liverpool
	11th Dec., 1889	Weatherilt, Arthur	Knowsley View, 24, Denton's Green Lane, St. Helens
1.	8th Nov., 1893	Webb, Walter H.	2, Boundary Road, Birkenhead
3.	7th Dec., 1881	**Webster, John J.,** M. Inst. C.E. *Past President*—1887.	39, Victoria Street, Westminster, S.W.
	30th Nov., 1904	Welbourn, Burkewood	Clarach, Rainhill, Lancs.
	18th Feb., 1891	Wells, J. M.	London Hydraulic Power Co., Palace Chambers, 9, Bridge Street, Westminster, S.W.
	25th Nov., 1896	West, Charles H., M.I.M.E.	5, Castle Street, Liverpool
2.	25th Feb., 1885	**West, Henry H.,** M. Inst. C.E., M.I.N.A., M. I. Mech. E. *Past President*—1889-90. *Member of Council.*	British and Foreign Chambers, 5, Castle Street, Liverpool
	8th Nov., 1893	Westharne, Henry G.	4, Kimberley Street, Liverpool
	7th Mar., 1900	Whalley, Alfred, M.I.E.E.	Ashville, Helsby, Near Warrington
	11th Nov., 1896	Wheeler, Percy	Oldbury Railway Carriage Company, Birmingham
	15th Nov., 1899	Wheelton, S. J.	City Engineer's Office, Municipal Buildings, Liverpool
1.	17th Nov., 1897	White, Joseph Walwyn	Huntley, Hunt's Cross, near Liverpool
	14th Dec., 1898	Whittaker, F. W.	The Bradford Dyers' Association, Ltd., 39, Well Street, Bradford
1.	19th Oct., 1887	**Wilcox, Ernest S.,** M. Inst. C.E. *Past-President*—1902-03.	The Bents, New Brighton
	26th Apl., 1899	Wilding, James	Surveyor's Office, Town Hall, Runcorn
	24th Jan., 1900	Wilkie, James B.	c/o Messrs. Elder, Dempster & Co., 56, Jamaica Street, Liverpool
	18th Nov., 1903	Williams, Daniel	Town Hall, Atherton
	3rd Dec., 1902	Williams, R. J.	16, Lord Street, Liverpool
	29th Apl., 1903	Wilson, Alexander C., Assoc. M. Inst. C.E.	45, Greenbank Road, Higher Tranmere
	30th Nov., 1898	Wilson, Henry B.	45, Derby Road, Farnworth, Widnes
2.	12th Mar., 1902	**Wilson, H. W.,** A.M.I.E.E. *Member of Council.*	Messrs. T. L. Miller & Wilson, 19, Brazennose Street, Manchester
	3rd Feb., 1897	Wilson, John	7, Beech Road, Higher Tranmere, Birkenhead
	16th Nov., 1904	Wilton, Thos. R., B.A. (Cantab), Assoc. M. Inst. C.E.	143, Hartington Road, Sefton Park, Liverpool
1.	5th Dec., 1900	Winder, Oliver, Assoc. M. Inst. C.E.	Overdale, Horwich, near Bolton, Lanc.
	19th Nov., 1902	Wolfenden, B. J., Assoc. M. Inst. C.E.	64, Merton Road, Bootle
	13th Nov., 1895	Wood, Herbert	26, Windsor Road, Tue Brook, Liverpool
	13th Feb., 1878 / 22nd Oct., 1884	**Wood, John Thomas,** M. Inst. C.E. *Past President*—1891-92.	Halewood, near Liverpool

	DATE OF ELECTION	NAME	ADDRESS
	25th Apl., 1900	Wood, William Brownbill	The Court, Halewood, Nr. L'pool
	12th Jan., 1887	Woodall, Corbet, M. Inst. C.E.	Palace Chambers, Bridge Street, Westminster, S.W.
	28th Jan., 1903	Woods, Edwin	Latchford, near Warrington
	11th Jan., 1893	**Woods, Arthur R. T.,** M.I.N.A. *Member of Council.*	c/o Messrs. Nelson & Co., 20, Castle Street, Liverpool
	4th Apl., 1900	Woollright, Percy	8, Croxteth Road, Liverpool
	18th Dec., 1901	Worthington, W. B., B. Sc., M. Inst. C.E., M.I. Mech. E.	Lanc. & Yorks. Railway, Engineer's Office, Hunt's Bank, Manchester
	30th Nov., 1904	Wright, Archibald E.	4, Ashlar Road, Waterloo, near Liverpool
	21st Feb., 1900	Wright, W. Ryle	Borough Electrical Engineer, Wellington, New Zealand
	16th Nov., 1904	Wyld, William. M. I. Mech. E., M.I.E.E.	26, Devonshire Road, Claughton, Birkenhead
	19th Nov., 1902	Wyles, David D., M. I. Mech. E.	1, Rutland Avenue, Sefton Park
	22nd Feb., 1899	Yates, F. Spencer, Assoc. M. Inst. C.E.	Town Hall, Waterloo, Nr. L'pool
4.	10th Nov., 1875	**Yeatman, Morgan E.,** M.A. Cantab., M. Am. Soc. C. E., *Past President*—1879.	Messrs. S. Pearson & Son, Ltd., 10, Victoria Street, S.W.
1.	24th May, 1876	Yerburgh, J. E., Assoc. Inst. C.E.	Wavendon Lodge, Woburn Sands, R.S.O., Bedfordshire
	14th Jan., 1880	Ziffer, Fredk. Henry (*Life Member.*)	

421 Total Number of Members

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

ASSOCIATE MEMBERS.

DATE OF ELECTION	NAME	ADDRESS
30th Nov., 1904	Brothers, Colin S.	42, Liverpool Road, Birkdale, Southport
3rd Dec., 1902	Edmondson, Jas. H.	Landgate, Brynn, near Wigan
30th Nov., 1904	Grierson, John	25, Derby Lane, Liverpool
6th Apl., 1904	Holmes, Geo. N.	"Clifton," Egremont Promenade, Egremont, Cheshire
19th Nov., 1902	Houghton, H. Johnson	Westward, Neston, Cheshire
18th Nov., 1903	Jackson, G. J.	"Westborne," St. Anne's-on-Sea
16th Nov., 1904	Latham, Henry R.	"Lyndhurst," Hooton, Cheshire
19th Nov., 1902	Mason, A. Stewart, Stud. Inst. C. E., P.A.S.I., M.R.S.I.	Water Engineer's Department, Municipal Buildings, Liverpool
9th Mch., 1904	Meiklejohn, James H.	4, Devonshire Street, Ardwick, Manchester
29th Apl., 1903	Montague, J. E., Stud. Inst. C.E.	
3rd Dec., 1902	Owens, F. J.	20, Church Street, Egremont, Cheshire
30th Nov., 1904	Ripley, H. Percy	
17th Dec., 1902	Taylor, W. F.	Acresfield, Nicholas Road, Blundellsands
26th Apl., 1905	Tippet, H. Jackson	8, Westminster Road, Birkenhead
16th Nov., 1904	Webb, James T.	4, Chapel Walks, Manchester
14th Dec., 1904	Whittington, W. Ewart	Resident Engineer, Board of Public Works, Kincasslagh, Co. Donegal
19th Nov., 1902	Williams, Harold C., B.A.	4, Derwent Square, Stoneycroft

17 Total Number of Associate Members

NOTE.—Figures prefixed to a name indicate the number of papers contributed and published in the yearly "Transactions."

W. prefixed to a name indicates the award of a "West Premium."
D. " " " "Derby Gold Medal."
S. " " " "Society's Premium."

ASSOCIATES.

DATE OF ELECTION	NAME	ADDRESS
13th Dec., 1899	Alcock, Charles	Royal Insurance Company, 1, North John Street, Liverpool
6th Apl., 1892	**Annett, R. C. F.**, Assoc. Inst. C. E., *Honorary Secretary.*	4, Buckingham Avenue, Sefton Park, Liverpool
30th Nov., 1898	Arnison, R. Frank	2, Gilda Crescent Road, Eccles, near Manchester
21st Mar., 1900	Banner, J. S. Harmood	Ashfield Hall, Neston, Cheshire
25th Jan., 1899	Barrow, Richard	6, Caroline Place, Claughton, Birkenhead
25th Jan., 1905	Belam, Commander Hy., R.N.	34, Bentley Road, Liverpool
15th Jan., 1902	Bentley, Francis	c/o Messrs. Isaac Bentley & Co., Adelphi Works, Salford, Manchester
18th Nov., 1903	Blake, L. R. S. C.	c/o British Thomson-Houston Co., Manchester
30th Nov., 1904	Burns, J. H.	Wirral Railway, New Brighton
2nd Mar., 1898	Bremner, W. T.	197, Great Howard Street, L'pool
6th Jan., 1897	Burrows, Freeman	Bayford House, Sutton, Surrey
11th Nov., 1891	Burrows, Herbert F.	8, India Buildings, Fenwick Street, Liverpool
26th Feb., 1902	Butterworth, E. W.	African Chambers, Old Hall Street, Liverpool
10th Jan., 1900	Dart, Richard, C.C.	Aigburth Drive, Liverpool
14th Jan., 1903	Davies, Peter	8, Cook Street, Liverpool
11th Nov., 1896	Docker, Frank Dudley	The Gables, Kenilworth
11th Nov., 1896	Docker, Ludford C.	Icknield Port Road, Birmingham
13th Dec., 1899	Dove, John M.	Liverpool and London and Globe Insurance Co., Dale St., Liverpool
21st Nov., 1900	Edmiston, James M.	B17, Exchange Buildings, Rumford Street, Liverpool
16th Nov., 1898	Edmondson, Robert Holt	Bryerswood, Windermere
19th Nov., 1902	Emery, Walter T.	Municipal Technical School, Byrom Street, Liverpool
30th Oct., 1895	Glover, J. H.	Bank Chambers, 60, Castle Street, Liverpool
19th Nov., 1902	Gossage, W. Winwood	Messrs. Wm. Gossage & Sons, Ltd., Widnes, Lancashire
16th Nov., 1898	Hughes, Robert John	Surveyor, District Council Offices, Penmaenmawr, North Wales
4th Apl., 1900	Jackson, Thomas H., J.P.	Manor House, Birkenhead
13th Dec., 1899	Jones, Sir Alfred L., K.C.M.G., J.P.	Messrs. Elder, Dempster & Co., Water Street, Liverpool
21st Mar., 1900	Jones, Frank	32, Daulby Street, Liverpool

DATE OF ELECTION	NAME	ADDRESS
13th Mar., 1901	Kelly, J. Dunbar	B, Queen Insurance Buildings Dale Street, Liverpool
11th Nov., 1896	Littler, Henry	Architect's Dep't, County Offices, Preston
18th Nov., 1903	Lloyd, T. Percival	43, Ullet Road, Liverpool
7th Feb., 1900	Low, John	110, Sheil Road, Liverpool
4th Apl., 1900	Macaulay, John	General Manager, Newport Alexandra Docks & Ry. Co., Newport, Mon.
11th Dec., 1895	Maples, Cecil E.	14, Cook Street, Liverpool
12th Feb., 1902	Maples, Herbert A.	3, Cook Street, Liverpool
15th Nov., 1899	Martin, L. W.	22, Sir Thomas Street, Liverpool
24th Feb., 1904	Martin, Howard E.	38, Elgin Drive, Liscard, Cheshire
25th Jan., 1899	Maxwell, M. H., J.P.	76, Canning Street, Liverpool
13th Nov., 1895	McClure, Wm. Lees, J.P.	Ivy Bank, Huyton
11th Mar., 1903	Moore, G. A., A.I.E.E.	Engayne, Spital, Bromborough
27th Nov., 1895	Nicholson, A. C., F.G.S.	12, Salop Road, Oswestry
17th Nov., 1897	Oppenheim, H. S., J.P.	St. Helens, Lancs.
12th Feb., 1902	Pearce, W. R.	Messrs. Frank Pearce & Co., 18, Chapel Street, Liverpool
15th Nov., 1899	Petrie, Sir Charles, J.P.	7, Devonshire Road, Princes Park
2.W. 8th Feb., 1893	**Pierce, Ernest W.** *Honorary Solicitor.*	Deputy Town Clerk, Municipal Buildings, Liverpool
25th Jan., 1905	Pooley, Walton S.	Homestead, Liscard, Cheshire
13th Dec., 1899	Rutter, Frederick W. P.	London & Lancashire Fire Insurance Co., Dale Street, Liverpool
8th Nov., 1893	Shone, J. Fowler	24, Fenwick Street, Liverpool
30th Nov., 1904	Smith, R. Bowman	14, Bidston Avenue, Wallasey, Ches.
16th Jan., 1901	Somerville, F. J.	24, Fenwick Street, Liverpool
8th Nov., 1893	Temple, John *(Life Associate)*	Warrington Wire Rope Co., 13, Goree Piazzas, Liverpool
14th Jan., 1903	Thomson, William	7, Cook Street, Liverpool
20th Nov., 1901	Wheeler, A. Henry	Plas-fr-giff, Trevor, Carnarvon
26th Apl., 1899	White, Herbert	Messrs. R. White & Sons, Widnes
31st Jan., 1894	Worrall, Ernest, M.R.S.I.	Surveyor, Old Trafford, near Manchester
1. 17th Mar., 1897	Young, Oswald W.	Egerton Park, Rock Ferry

55 Total Number of Associates

N.B.—For the convenience of members wishing to communicate with the Hon. Secretary upon matters pertaining to the Society, time will be saved by addressing him at his private residence, as above given.

STUDENTS.

	DATE OF ELECTION	NAME	ADDRESS
	16th Nov., 1898	Adamson, Richard A.	Liverpool Corporation Water Works, Horwich, near Bolton
	25th Mar., 1903	Aylward, Richard N.	32, Elm Road, Seaforth, near Liverpool
	21st Nov., 1900	Beloe, Wilfrid, Stud. Inst. C.E.	"Redcliffe," Linnet Lane, Liverpool, S
	8th Feb., 1905	Davidson, George L.	98, Whitechapel, Liverpool
	16th Apl., 1902	Denbigh, Edward Bisset	St. Hilda's, Ashlar Road, Waterloo, near Liverpool
	21st Mar., 1900	Duncanson, Alec. W., B.Sc., B. Eng., Stud. Inst. C. E.	16, Deane Road, Liverpool
1.	24th Jan., 1900	Flinn, Hugo	15, Highfield Street, Liverpool
	11th Nov., 1903	Galloway, J. Bruce	31, Crosby Road, Birkdale, Southport
	21st Mar., 1900	Giles, Humphrey N., B. Sc., B. Eng., Stud. Inst. C. E.	8, Salop Road, Oswestry
	11th Dec., 1895	Hatton, Ernest	Tramways Manager, Newcastle-on-Tyne
	30th Nov., 1904	Howarth, Mark, Junr.	7, Breckside Park, Liverpool
1.	15th Nov., 1899	Leighton, Arthur, B.Sc., B. Eng., Stud. Inst. C.E.,	c/o Messrs. S. Pearson & Son, Ltd., 10, Victoria Street, Westminster, London, S.W.
	16th Nov., 1904	Lorraine, Jos. W.	17, Priory Street, Birkenhead
	30th Nov., 1904	Mahon, F. J.	46, Norwood Grove, Liverpool
	11th Feb., 1903	Miller, John W. A.	49, Westbank Road, Devonshire Park, Birkenhead
	5th Dec., 1900	Mitchell, Alex. C., Junr., Stud. Inst. C. E.	6, Rocky Bank Road, Birkenhead
	19th Feb., 1904	Nicholson, E. D.	12, Salop Road, Oswestry
	22nd Mar., 1904	Sampson, C. D.	52, Bridge Street Row, Chester
	18th Nov., 1903	Shelmerdine, Eric D. S., Grad. I. Mech. E.	Electricity Central Station, Stretford, Manchester
	21st Mar., 1900	Stott, Harold	
	17th Dec., 1902	Shawe, J. W.	Bank House, Ormskirk, near Liverpool
	16th Nov., 1904	Ten Bosch, John, Junr.	13, Abercromby Square, Liverpool
	10th Jan., 1900	Tippett, Philip V.	c/o The Farrel Foundry and Machine Co., Ansonia, Conn., U.S.A.
	4th Apl., 1900	Tredcroft, A. F., Stud. Inst. C.E.,	32, Elm Road, Seaforth, near Liverpool
	18th Nov., 1903	Ward, H. Bernard, B. Sc.	The Elms, West Kirby
	24th Jan., 1900	Wollaston, C. H. P.	32, Halville Road, Smithdown Road, Liverpool

26 Total Number of Students

528 Total Number of Members, Associate Members, Associates and Students

George Reed & Co., Printers, 40, Paradise Street, Liverpool.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

FIRST MEETING—2ND NOVEMBER, 1904.

MR. THOMAS L. MILLER, M. Inst. C.E., M.I. Mech. E., M.I.E.E.,

The Retiring President,

INTRODUCED TO THE MEETING

Mr. FRANK E. PRIEST, M. Inst. C.E.,

The President-Elect,

WHO THEREUPON TOOK THE CHAIR.

INAUGURAL ADDRESS.

GENTLEMEN,

In accepting the honour which you have conferred upon me in allowing me to occupy the Presidential Chair this Session, I feel that this is another instance of the consideration and kindliness that has always been extended to me by the Members of the Society during the 18 years that it has been my privilege to belong to it. At the same time it is not without misgiving that I enter upon the duties of the office, having regard to the imposing list of Presidents who have preceded me, and also having regard to the fact that our Society occupies so important a position in the profession of Engineering in this country; a position fortified with traditions, for, although the Society cannot be said to have an ancient past, it is old enough to have remaining upon its roll only three members who joined its ranks during the year of its inauguration.

While it would appear that engineers before our own time had yet to learn the advantages of association it may be not without value that, when we are assembled as we are this evening, we should reflect upon the antiquity of engineering as a scientific profession.

I am not now referring to those instances of engineering achievement

which from time to time have been referred to in the history of the ancient world, but am content to confine the consideration to the history of our own land during the growth of our nation. I am led to refer to this subject by being reminded from time to time of a popular misapprehension concerning the genesis of engineering, wherein it is assumed that, from the ancient profession of architecture, a modern offshoot has developed which we are pleased to brand with our name. Even engineers are sometimes to be found who are not disposed to controvert this fallacy. In this connection it is interesting to notice that while Dr. Murray gives references to the title "Engineer" from the year 1325, those relating to our cousin, the Architect, only begin in 1563, or nearly two-and-half centuries later. I neither wish nor am able to occupy your time upon matters of archæology, but, before leaving this subject, I would remind you that we were represented locally in the thirteenth century by an engineer of great achievements, Richard, the engineer, long resident in Chester, who built the castle of Flint, restored that of Rhuddlan, was called in by the Abbot of Saint Werburgh's, Chester, to advise and carry out the restoration of parts of the Abbey, was the lessee of the famous Dee Mills, and, I believe, reconstructed in part the Roman weir adjacent to them. Not unlike some of us to-day he sought municipal honours, and occupied the mayoral chair of Chester in 1304. Here is an instance of one of us whose works are standing to-day after seven centuries of battering by man and the elements, demanding the admiration alike of the informed and the uninformed, and proving that if we did not come over with the Conqueror we enabled his descendants to stay.

I suppose it may be said that professions generally are the children and the servants of civilization, if by that term we understand those methods and habits of life of which we are proud, and which in most cases seem to be most remarkable as departures from the intentions of nature. It would afford interesting meditation to consider what would be the direction of the scientific efforts of engineers if civilization and all its wants and ways were removed from their environment, but however interesting this might be it takes no part in the necessary curriculum of the engineer, and calls for no further comment here. Certain it is that the progress of civilization has gone hand in hand wtth the development of engineering, and it might not be time wasted if for a few minutes we consider this association in one aspect.

It was pointed out in the address of Sir John Wolfe Barry on his assumption of the Presidency of the Institution of Civil Engineers in

1896 that the whole population of the world could stand upon the Isle of Wight, and yet, although, in making this statement, he was allowing the population a little more room than customarily is occupied by crowds, wherever a relatively small part of this population has been placed, the disposal of its sewage has not only presented great difficulty, but has for generations been impossible of attainment without great nuisance, injury to health, and other evils.

No better example of the interdependence of civilization and engineering could be found than that exhibited in the sewage problem.

While man was content to lead a nomadic life the natural operations of his body were in unison with, and indeed formed an important part of Nature's programme, but no sooner were the habits of civilization acquired than the resentment of Nature at the interference with her methods began to be felt.

The aggregation of man in towns not only robbed nature of a part of her sustenance, but caused the accumulation and decomposition of putrescible matter with the consequent emanation of foul smelling and poisonous gases within or adjacent to the dwellings of man. The abatement of this nuisance has always been a serious problem, and is so to this day, and unless man is content to distribute himself sparsely over the surface of the earth will for all time call for the operations of the engineer working together with the men of other sciences.

Theories and systems of remedial requirements have always been prevalent.

The Tudor and the earlier Stewart kings forbade the further growth of London by immigration in order to check the increasing nuisance, although the Stewart London was as a village compared with very many of our provincial towns of to-day. In more recent times Acts of Parliament have been passed in order to stimulate the desire for clean surroundings and pure streams, and although much has been done with the intention of effecting the disposal of the sewage of our towns and larger villages, that is, to this day, one of the chief duties of the engineer. It was, however, only about the middle of the last century that it was recognized as an engineering problem in this country.

The first report of the Commissioners for enquiring into the state of large towns and populous districts, issued in 1844, shows that out of 50 of the principal towns in the country exclusive of the metropolis, only five were provided with sewers, which, even according to the officials of these towns, could be considered efficient.

In answer to the question: "Are there any sewers or branch drains in "the streets," the reply of Liverpool was, "Sewers in the main streets, "courts and alleys neglected; refuse rots on the surface; the liquid "matter is absorbed and finds its way into the cellar." Liverpool thus laid bare its own imperfections fully, but although the replies from other towns were less explicit, it is clear that in most cases the arrangements were no better. Thus, Gloucester said it had "No "system of drainage." Durham pronounced its drainage "partial "and very defective." Chester seems to have made arrangements on paper, as its reply was, "Not enforced for want of funds, greater "portion wholly without drainage." West Bromwich was content to reply phlegmatically, "None."

It is not surprising to find that the average death rate in 36 of these towns for the years 1840, 1841 and 1842, was 27 per 1000, nor on considering the answer of Liverpool just referred to, to find that it towered above its fellows with a death rate of 35 per 1000 during the same years.

Even where sewers were constructed the use for which they were intended was of little value, as house drains were not allowed to be connected with them, and the state of towns then was analogous with that of many hamlets now in which highway drains are the only means of carrying the waste liquids from the houses, the liquids being thrown on to the road to find their way into the drains through the roadside channels.

It is not easy for a dweller in a large town to-day, mentally, to reconstruct the condition of affairs existing during the first half of the last century.

The disposal of the sewage was in effect at that time left to the inhabitants individually. The solid dejections were carried from the houses and buried, and the liquids were allowed to run in open channels, into pits, from which they were subsequently distributed over gardens or buried with the solids. Where the houses had sufficient land this arrangement might be quite satisfactory, if somewhat inconvenient, but in cases where houses were crowded together, as in the poorer parts of the towns, the nuisance produced by this method must have been terrible, and the results upon the health of the inhabitants disastrous.

The introduction of privies and middens saved the necessity of the conveyance of part of the solid dejections about the premises, but made no improvement in the sanitary conditions. Where the middens were water-tight the liquid sewage which entered them together with

that part of the solid which became liquefied by the natural process which at that time was not understood, reduced the whole mass to a seething puddle, filling the surrounding air with a loathsome stench, and poisonous gases. Where, as was commonly the case, the middens were not water-tight, the drainage containing the foulest of the sewage passed away into the ground, where it was likely, too frequently, to find its way into wells, whence was taken the water supply for the houses. Such of the solids as were not liquefied accumulated until the chamber was full, when the whole would be dug out, and carted away, not infrequently being carried through the houses, that being the only means of communicating with the back premises where the privies were placed.

Even at this time the manurial value fallacy had obtained a grip upon the imaginations of enthusiasts, and it was boldly asserted that the filth lying in the middens had in it such value as would pay for its handling, carting and distribution as manure. It was not recognized then, as frequently it has failed to be recognized since, that by far the greater part of the manurial constituents of sewage is to be found in the urine, which as a rule was lost before the remainder reached the land. Considering the nuisance that arose from the detention of the urine in the middens, it is not surprising that an effort should be made to ensure its escape, and when drains existed in the neighbourhood of the middens illicit connections were frequent into them. Consequently, although as a rule these drains were only laid for the purpose of carrying off the surface waters, they became in effect sewers, taking the strongest part of the sewage to outfalls into streams, which consequently became polluted.

Bad as was the midden and cesspool system at its best, occasionally eccentricities were met with which make one shudder even to think of. Of such, one is described by the Rev. J. Clay, in a report on the sanitary condition of Preston, printed in Vol. I of the first report of the Health of Towns Commission, 1844. In this case two parallel rows of cottages had, at their back, yards 10 feet long from house to wall, and between the yard walls of the two rows was a space four feet wide, corresponding with that commonly occupied by a back passage, but here it was a ditch, or cesspool, into which all the sewage from the cottages fell, and lay until the accumulation was sufficient to cause it to flow along an extension of the ditch beyond the houses.

Another instance of misdirected ingenuity was to be seen a few years ago, not far from this city, where in front of a row of cottages were placed small buildings opposite every fourth cottage. Under

the one roof of every one of these buildings were a privy, with a midden, a pigstye which also drained into the midden, when the midden did not drain into the pigstye, a coal store, and a baker's oven.

The state of things disclosed by the report of the Commission of 1844 demanded and secured the attention of the Government, and in 1848, and in subsequent years, were passed the series of Public Health Acts, under which progress in this branch of Engineering was begun.

In 1865 the Sewage Utilization Act also was passed, having for its object the extension of the powers of the Public Health Acts to Districts excluded in those Acts.

Consequent upon this legislation operations were commenced all over the country for better means for the disposal of sewage.

It is noticeable that the commercial spirit is mostly to be found in the various undertakings. So great was the expectation of profit from the use of sewage, that in Liverpool two companies were formed and competed for the concession, from the Corporation, of the right to take sewage and pump it into rising mains, whence it was to be distributed over farm lands to the North of the town, which were to be enriched by the fertilizing fluid, and for this advantage the farmers were to pay sufficient rates to cover the outlay and expenses. The concession being granted to one company the works were constructed and put into use, but it is sad to have to relate that the results were not such as justified the continuance of the operations.

Under the powers of the Acts towns provided themselves with sewers into which the sewage from the houses was allowed to be discharged, and thus the sewage problem became confined to the treatment of the sewage at the point of outfall so as to stop the pollution of the stream.

With few exceptions it was accepted that water carriage was the necessary means of conveyance of the whole of the sewage to the outfall, and consequently the only problem became the purification of sewage in liquid form.

Some towns—notably Manchester—endeavoured for many years to avoid water carriage, but it is fair to say that the general experience of such towns has been that, while the dry collection of the sewage solids has created an independent nuisance, the operations attending the disposal of the liquid sewage have still to be carried out on practically as extensive a scale as in places where water carriage alone is used. This need not be a cause of surprise when it is borne in mind how small a percentage of the average daily quantity of sewage per head of the population are the solid fæces discharged by one person.

The average weight of the fæces discharged per diem may be taken at $3\frac{1}{5}$th ounces, while that of the urine is about $41\frac{1}{4}$ ounces.

In large towns the quantity of sewage discharged is seldom less than 30 gallons per head of the population per diem. The greater part of this is water which has been used for domestic purposes, and during that use has become fouled in various ways, and causes as great a nuisance during the process of putrefaction as does the actual waste from the bodies of the inhabitants.

It is evident, therefore, that after the removal of the $3\frac{1}{5}$th ounces of solids and such small parts of the urine as could be collected by any of the methods adopted for the purpose of dry carriage by far the greater part of the sewage remained to be dealt with as water carried sewage.

Early in the second half of the last century the purification of sewage had become a battlefield for partisans. On the one side it was contended that the only proper means of purifying sewage was its disposal on land; on the other side treatment with chemicals was upheld as a sure means to a satisfactory end.

The advocates of the land treatment vigorously maintained, as they do still, that unless the sewage were given back to the land from whence its constituents had been obtained, the land would be robbed of its proper nourishment and financial ruin would follow, and at the same time maintained that the processes of nature whereby the constituents of sewage would be dealt with as plant food would bring about the purification of the sewage, and prevent the pollution of the rivers of the country.

These people did not condescend to explain how land in this country, which in many seasons becomes unproductive because of the excessive moisture to which it is subjected, was to withstand, in addition to that excess of moisture, a further load many times greater than the original burden, and, at the same time, to produce crops profitably.

The chemical advocates endeavoured to prove that by the addition of various chemicals such of the sewage as remained solid at the outfall could be deposited in tanks, and that which was in solution could either be precipitated or rendered innocuous.

Both parties to the quarrel were right in principle in claiming for their agent the power of purifying sewage, but in both cases it was found impossible to obtain satisfactory results without very large expenditure. So long as the old ideas of the commercial value of the sewage continued, expenditure for its treatment could only be induced

by promise of profit by the sale of crops or of manure derived from the sewage, and when these promises were not fulfilled the purse strings were tightened, and the treatment failed. Nevertheless great sums were expended in putting these ideas into practice. Amidst innumerable failures an occasional success owing to peculiar conditions would be hailed as proving the contentions, and frequently would become sufficient to urge on lagging communities to follow the advice of the partisans. Unfortunately, notwithstanding these attempts, the rivers of the country continued to become more polluted, and consequently, in 1865, a Royal Commission was formed to report upon the question. Three years later the appointment of this Commission was revoked, and its duties transferred to a new Commission, the reports of which had a very marked effect upon the operations for sewage treatment in the period following.

The first report brushed aside the claims of the dry carriage system for towns. The claims of chemical treatment received little more consideration. The fantastic A B C process was left over for further consideration, while the most favourable opinions were expressed about filtration through soil, provided that the rate of filtration be sufficiently slow. It was pointed out that at Ealing filtration in artificial filters had failed to produce any beneficial effect, because of the small area of filter employed, and because the direction of flow through the filters was upward instead of downward. At this time Ealing was attempting to purify 400,000 gallons of sewage per diem by letting it rise through 60 cubic yards of burnt clay ballast, after settlement in tanks. The passage of the sewage through the filter was at the rate of 2,222 gallons per square yard per foot deep per diem, and the Commissioners stated that even if proper provision for æration of the material were made the rate should not exceed $3\frac{1}{3}$ gallons per square yard per foot deep per diem, or a rate 666 times slower than that then obtaining. This opinion was based upon a series of laboratory experiments, which probably have had great influence in subsequent work. At the time, the sewage question was in the throes of a discussion far too hot for the placid acceptance of any opinion, and the reports of the Commission were subjected to a full measure of discussion and dissent. It is remarkable, in the first report of this Commission, how, without knowledge of the operative forces, the effects and requirements of filtration are described with precision. Naturally, from the incomplete information, only incomplete or erroneous results could come, and we do not find that any material advance in the actual purification of sewage was made

for a quarter of a century, but the knowledge was being obtained during that period, and I believe that this first report was the platform from which most of the subsequent investigation proceeded.

Up to this time there had been introduced treatment by broad irrigation, by intermittent filtration, and by the use of chemicals.

Irrigation in some form had been in use since the second half of the seventeenth century. Intermittent downward filtration was new. Chemical treatment began apparently with the use of lime under a process patented by one Higgs in 1846.

Higgs had been followed by a host of others, who ransacked the earth for nostrums with which to tempt the defaulting authorities. Lime played a part in most prescriptions, but sulphide of iron, chloride of iron, sulphate of alumina, coal dust, and a host of other substances were used.

One pair of inventors were only content with a natural phosphate of alumina, which was imported from the Island of Altavolo, which geographers say is to be found in the East Indies. For breadth, however, these all paled before the process known as the A B C, of which the purifying agents are given by the inventor as follows :—

Alum	600	parts.
Blood	1	"
Clay	1900	"
Magnesia	5	"
Manganate of Potash	10	"
Burnt Clay	25	"
Chloride of Sodium	10	"
Animal Charcoal	15	"
Vegetable Charcoal	15	"
Magnesian Limestone	2	"

One cannot but respect a man who could think of so many things to put into sewage, but at the same time one cannot but feel that he had missed an opportunity in not continuing his list in the words of another poet almost greater than himself :—

> "Eye of newt, and toe of frog,
> Wool of bat, and tongue of dog,
> Adder's fork, and blind worm's sting,
> Lizard's leg, and owlet's wing."

Out of the 2,588 parts of all the mixture it is evident that the one part of blood must have been a very important factor in the process. It was also important in providing the initial "B" to go between the initials of alum and clay in order to get the trade tag "A B C." But here again was a lost opportunity, for surely whatever value there

might have been in blood the really potent article should have been taken from a baboon, unless the witches of Macbeth did not know their business. Long as was the list of materials used, strange to say the life of this process also has been phenomenally long, for notwithstanding that after prolonged trials in several places it was customarily discontinued, it never failed to reappear and claim its powers in new fields as opportunities arose.

During the eighties of last century attention was drawn to two other directions in which the purpose might be effected. On the one hand filtration through artificial beds of various materials other than soil, and on the other hand artificial oxidation of the sewage was resorted to. It was found that beneficial results, in many cases, were obtained by the use of such materials as cinders and gravel, but in most cases the advantages appeared to be temporary only, and although remarkable results were obtained in certain instances, usually continued working brought about very marked deterioration in the effluent, until in time no improvement, and frequently apparent deterioration, resulted from the filtration.

Various mineral substances for which the vendors claimed particular virtues, chiefly by reason of their having in their constitution various salts of iron, were used in considerable quantities under trade names which served as battle cries in several fights before Parliament and other tribunals, and their action upon the sewage was described explicitly, but, as it would now appear, with absolute inaccuracy.

The efforts artificially to oxidize the impurities of the sewage were perhaps more scientifically correct, and at the same time more practically hopeless, as, although, in experimental installations, sometimes very satisfactory results were obtained, it was too apparent that the cost by which this end was effected was so great as to make the operation an impossible one for the whole of the sewage of towns.

The general view of the operation of these processes was that by them the organic matter in the sewage was brought into intimate contact with nascent oxygen in the one case, or with oxygen in some peculiar condition in the other case, and that thereby oxidation was effected. While this did represent the effect in the artificial oxidation processes, it is now known to be very far from the explanation of the operations of the filter beds.

About the time of the introduction of sewage irrigation in Great Britain, when the sewage of Edinburgh was first placed upon the sands of Craigentinny, *i.e.*, when the seventeenth century had completed three-quarters of its course, workers with the miscroscope were

beginning to discover the existence of organisms so small as only to be visible under the highest magnifying powers then obtainable. The credit for this discovery was claimed for one Athanasius Kircher, a German Jesuit, and also for Leeuwenhoek, who described them as "animalcules many thousand times less than a grain of sand, and in "proportion to a mite as a bee is to a horse."

Progress seems then to have ceased for a time, but near the end of the eighteenth century a classification of the bacteria then known was attempted by a Dane, named Otto F. Müller. In 1838 a German, by name Christian Gottfried Ehrenberg, re-introduced the subject with his work, " Infusorial Animalcules as complete Organisms."

Knowledge continued to increase, but it does not seem to have impressed the workers with other than the baneful influences of the organisms.

While in the province of pathology much information was being acquired, the benevolent influences seem not to have been understood, or to have made their importance felt, and therefore the minds of men were turned rather to the means for the destruction of the microbe than for its cultivation or use. It is little to be wondered therefore that among the many fertile brains that were devising nostrums for the conversion of sewage into valuable, if not delectable substances, the gigantic powers of the smallest of God's creatures now known to us had not received attention.

An exception to this inattention is to be found, however, in an article contributed by the Abbe F. Moigno to "Cosmos," in December, 1881, and January, 1882, where, after describing an invention patented by Monsieur Mouras for an appliance for sewage purification, he says, speaking of the destruction of fæces in the apparatus, " May not the "unseen agents be those vibrones or anærobies, which, according to " Pasteur, are destroyed by oxygen, and only manifest their activity in " vessels from which the air is excluded."

This invention of Mouras, which he called an automatic scavenger, was merely an air-tight cesspool, in which the entering pipe had its opening carried to a point below the standing level of the contents, and its outfall carried down similarly so that both inlet and outlet were trapped. The inventor pointed out in his patent specification that all manner of refuse, provided it was not broken pottery, and such indigestible articles, was rapidly dissolved, and destroyed in his apparatus, and that as sewage flowed in on the one side, a purified water flowed out on the other. This invention does not seem to have been recognised by later rivals, nor does the correct surmise of

the Abbe Moigno appear to have received any credit from later biologists until Professor Boyce, of our University, drew attention to the article.

In 1888 the Massachusetts State Board of Health laid down at Lawrence a large experimental station with the object, as stated in the original report, of learning how to purify sewage. Fortunately the experimenters do not appear to have been restricted in the cost of the experiment, and, also fortunately, men capable of learning the lessons that the works were teaching were engaged upon the experiments. A further fortunate circumstance was probably the fact that American sewage is much more dilute than that commonly flowing from English or Continental towns, and consequently the results at the experimental station were more favourable, in the first instance, and so encouraged the observers, and enabled them more easily to deduce from them the hypotheses upon which to found the true method for adoption in practice.

The experimental plant consisted of ten circular tanks 17 feet in diameter and 6 feet deep, with means for controlling the passage of sewage into and out of them. The tanks were filled with various kinds of sand, peat, river silt, soil, gravel, and clay. A laboratory was erected at the station, and a series of experiments was begun, and is still being continued.

The Commissioners state in their conclusions in the first report that, "With the gravels and sands, from the coarsest to the finest, we "find that purification by nitrification takes place in all, when the "quantity of sewage is adapted to their ability, and the surface is "not allowed to become clogged by organic matter to the exclusion "of air."

They point out that by the slow passage of the sewage through the filter they were enabled to remove 97 per cent. of the organic nitrogenous matter, a large part of which was in solution, as well as 99 per cent. of the bacteria, these organic matters being oxidized or burnt into harmless mineral matter. They stated that the essential conditions were very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid, and "with these conditions it is "essential that certain bacteria should be present to aid in the process "of nitrification. These, we have found, come into the sewage at all "times of the year; and the conditions just mentioned appear to be "most favourable for their efficient action, and at the same time most "destructive to them, and to all kinds of bacteria that are in the sewage."

They state also that experiments as to the effect on filtration of the exclusion of air, produced results similar to those produced by continuous filtration, when no nitrification takes place, and the effluent gradually becomes worse, until it contains as much organic matter as the sewage.

This report was the foundation and the stimulant for the experiments in bacterial treatment which followed soon after.

Mr. Dibdin, at Barking, proceeded experimentally to treat the London sewage with filters formed of pea ballast, coke breeze, burnt clay, and one of the patented materials then being exploited. The results obtained being sufficiently satisfactory, a filter, one acre in area, formed of coke breeze, was then constructed and worked in 1893, and the results obtained were so satisfactory that the attention of the whole country was attracted by them, and Barking became a "Mecca" for sanitarians.

The success of these biological experiments led to the hope that the great difficulty of all processes, *i.e.*, the disposal of the sludge, had been overcome. It had been shown previously that by the use of large quantities of chemicals, and proper sedimentation or precipitation, great quantities of solids could be taken out of the sewage. Of these solids most had been in suspension, but some were recovered from solution, and when this had been done the liquid in some cases was capable of material improvement by filtration, but in overcoming the initial difficulty it was found that another no less had been created, and while the liquid could be disposed of, the sludge remained to be a greater nuisance than the sewage from which it had been taken. It was only natural therefore that Corporations and Councils labouring under this sludge difficulty should hail with delight a process which seemed to remove their troubles. The first flush of exultation, however, was checked when it was discovered that great care had to be exercised in order to avoid the choking of the surface of the beds by the coarser matters of the sewage discharged upon them. When this necessity impressed itself upon the interested watchers, Mr. Cameron, of Exeter, introduced to them the septic tank, the purpose of which was not to purify, but to liquefy the sewage on its way to bacterial filters for purification. This septic tank is nothing more nor less than Mouras's Automatic Scavenger. In its turn it was regarded as the means of removing the sludge difficulty, and in large measure it is that means, for practically all the organic matter that enters it in solid form may be caused to leave it in solution, but after this has been done there remains a considerable quantity of inorganic substances

—Mouras's crockery—and some organic substances so tough as to defy the digestive capacities of the denizens of the tank.

Contemporaneously with the septic tank Mr. Scott-Moncrieff carried out and published a series of experiments for the liquefying of the solids of sewage by the same agency, but in a different form, and several other workers have dealt with the methods of filtration for the purification of sewage.

The prime necessity in the filters is the free admission of oxygen, as was pointed out in the Massachusetts' report. To effect this several devices for casting the sewage on to the surface of the beds by means of spraying or raining so as to carry with it as much oxygen as possible, obtained by contact with the air, and others for the passage of air into the body of the filter through openings in the walls and floors, have been devised. This is a field for invention in which there is still ample room for workers, but it is essential that simplicity should be the leading characteristic of the appliance, as in no operations more than in the purification of sewage is it imperative that there should be absence of complication and liability to get out of order.

Let us now give some few moments to the consideration of the causes producing the changes in sewage in bacterial treatment.

It is difficult to form any exact idea of the organisms by whose favour we are enabled to live. Their size cannot be stated in terms that we can appreciate. There would appear to be giants among them as well as pigmies, but whether they be giants or whether they be pigmies, no scale that we can set up enables us to measure them. Dr. Houston states he found that 1,800,000 weighed ·0000147 gramme. A cubic centimeter has been known to afford accommodation for 24,000,000 organisms. I do not suppose those figures convey any ideas of weight or size to any one. Certain of these organisms have constitutions which are not susceptible to changes of climate, as, for instance, those which were found by Macfayden and Rowland to survive a temperature of – 258 degrees centigrade.

Reference was made earlier to the separation of organisms by Pasteur into two groups, namely, those which require oxygen and those which require its absence for their active life. These are known as aerobes and anaerobes respectively, and this division is a very important one in the treatment of sewage. While the kinds of organisms are extremely diversified they are capable generally of classification under these two heads, but there is also a class which

combines the characteristics of the two groups, having constitutions so conveniently arranged that they can suit themselves to their environment and so work out their mission in life either with or without the assistance of oxygen. Those which do not require air—the anaerobes—are those by which liquefaction is carried on in septic and Scott-Moncrieff tanks, and also establish themselves in filters into which, for some reasons, the necessary amount of oxygen to support the aerobes is not admitted.

Observations of the habits of my fellowmen leads me to think that possibly analogous classes could be found among them. Judging from the atmosphere of many houses, churches, railway carriages and other places, the anaerobes must be very numerous.

Among the micro-organisms the aerobes are those which effect the nitrification of the nitrogenous matters which pass into the filters. While, therefore, the anaerobes serve a good purpose in the initial work upon the putrescible solid matter of sewage it is to the aerobes that we have to look for the actual purification. The engineer finds these willing agents always at hand ready to occupy the habitats that he prepares for them, and eager to fulfil their purpose which is as important as that of any creatures in the Universe. This sounds extremely simple, but in its application there is ample scope for skill and ample opportunity for error.

How is the question of the manurial value of sewage affected by the development of bacterial treatment? may be asked, and I think the answer to it must be that if there be any commercial value in sewage it is by this process that we may expect to secure it.

Without doubt there is in all sewage some organic matter capable of resolution into plant food, but it is carried in so vast a quantity of water relatively that the mixture may be regarded as an ore of so low grade as to be not worth working. But whatever the value of the constituents, they only become plant food when they have undergone the processes wrought by the organisms in the artificial filters or in the land. If, then, the manure be worth saving it will be found in the effluents from the filters in a condition suitable for absorption by the plants. Without pretending to deal with a chemical subject with the knowledge of a chemist, it may be permissible to say that the purpose of sewage treatment is the breaking up of the organic substances therein and the combination of the nitrogen and carbon, so disentangled, with oxygen. In this way nitrates are formed, and, being carried in solution, are available as food for plants.

Looking back upon the tales that we have been engaged upon

to-night one cannot but express surprise that man should have been so long in coming to some understanding of this elementary operation of nature, for it must be remembered that if the process which we have now been considering had not been instituted by nature from the beginning, life upon this globe would long since have ceased to be possible.

We have only to remember that the dejections of all animals in the form in which they leave the bodies are poisons to all except the lowest forms of life, for it to become clear to us how essential is the destruction of these dejections by some means, and yet the quantity of them, the destruction of which has ever been attempted by man, is insignificant compared with the remaining quantity which has been left to nature. Not only has this natural destruction been carried on under normal conditions, but in such abnormal conditions as have been set up by the habits of civilization. Even in cases where the herding of populations in confined spaces has taken place without any proper provision for the removal of the filth, the purification has gone on although it has been accompanied with those penalties which must be expected when natural laws are set at defiance. We may congratulate ourselves to-day that the twentieth century has dawned upon the possession of knowledge in this subject which enables us to avoid the evils of the past and encourages us to hope for greater advancement in the future. For it must not be supposed that we have arrived at a full knowledge of the subject. So far from this being the case we are probably only entering upon it.

While the best effluents that can be produced by bacterial treatment are often chemically satisfactory, they contain in most cases very large numbers of organisms. Of these the majority are benevolent, but pathogenic germs are there also, and therefore the danger of the spreading of the disease is present.

To meet this potential danger it has been suggested that there must be added to the treatment some finishing process to destroy the bacteria. This has suggested a new opening for the use of chemicals either by addition or by changes produced electrolytically. Probably it will be long before it will be possible to ensure chemically and biologically harmless effluents from the treatment of sewage, and possibly when that end has been attained it will not be by dosing but rather by following the methods of nature with care and knowledge. It may be that it will not be found necessary to destroy the whole of the organisms in sewage effluents in order to prevent the passage of the malevolent individuals into the streams. It is not improbable

that a way may be found for the destruction of the pathogenic germs by creating an environment unsuitable to them, and at the same time beneficial to those bacteria upon which improvement in the effluent depends.

The Royal Commission which was appointed in 1898 to report upon the treatment of sewage is still collecting information.

It has published already nearly 3,000 pages of reports, including a large amount of research work. It is impossible to say to what extent the labours of that august body may influence the methods of treatment of sewage, but whatever the principles ultimately laid down may be, it will remain the duty of engineers to apply them. I said early in the evening that this is a very important branch of engineering, and now I add that, despite the fact that to many here these references to it must have been wearisome, there are few more interesting.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

SECOND MEETING—16TH NOVEMBER, 1904.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. OTTO A. BLEY, GEORGE R. BRACE, CHAS. R. BRADY, GEORGE H. DUTTON, JOHN A. GRIFFITHS, J. GRUNDY, R. W. KNOLLYS, C. B. NICHOLS, H. E. O'BRIEN, WALTER PARRY, T. THORNEYCROFT-VERNON, and WILLIAM WYLD, as *Members;* Messrs. HENRY R. LATHAM and JAMES T. WEBB, as *Associate Members;* and Messrs. JOS. W. LORRAINE and JOHN TENBOSCH, Junr., as *Students.*

SOME ENGINEERING PROBLEMS IN GAS WORKS.

BY E. ALLEN, M.I. Gas E.

THE manufacture of gas, as indeed the systematic production of any commodity, involves the successful solution of many engineering problems. The designing of suitable plant and machinery and their careful construction on lines of economy and efficiency is work that calls for much skill and attention. Nor can the engineer be dispensed with when the installation is completed and ready to fulfil the intentions of its designer.

The production of motive power, its application to the various machines, and the successful working out of the processes that eventually lead up to the perfectly finished article or material, needs the constant supervision of the engineer. Repairs must be effected, breakdowns must be anticipated by intelligent observation, and the running of the works affords ample scope for the application of science and experience. Nor should the man in charge confine himself to

the maintenance of the plant in its original form, but should be ever on the alert to modify and alter it so as to "keep it up to date," or, in other words, he should be in touch with the engineering world and eager to notice any idea that can be applied to the improvement of his own works.

At the same time caution is necessary, and there are many questions to be satisfactorily answered before adopting new machinery, new plant, or new methods of work.

The financial question, or "will it pay," is of paramount importance. Labour saving contrivances are very attractive to an engineer—the uniformity of working—the substitution of a few skilful mechanics for a gang of labourers (who in reality earn their bread by the sweat of the brow)—the independence of the labour market with its sometime union tyranny—all these strongly bias the engineer in favour of the machine. But if the work be intermittent or only required during a short period of the year, the financial aspect of the case will be in favour of the man with the shovel and barrow.

Capital expenditure and the cost of upkeep and repairs make a heavy charge on machinery that is standing idle more than half the time, therefore, whilst the theorist or amateur engineer would lightly adopt machinery in place of manual labour, the practical man would satisfy himself of the financial soundness of the proposal before recommending the installation.

With these introductory remarks we will direct attention to some of the many problems to be found in a gas works.

It is truthfully said that "Dividends are earned in the retort "house," and therefore this department claims very special attention.

The problem is: "How best to transfer and transform coal at one "end into gas at the other."

This resolves itself into many sections or sub-problems.

For instance, say the coal is delivered by the contractor in canal barges alongside the works, and has to be taken out of the barge, weighed, and conveyed to the retort house. The elementary method of doing this is to employ the man with a shovel to go into the barge and fill the material into a barrow, which is then wheeled by another man on to the bank, weighed on a machine, and by several stages is finally deposited on the floor of the retort house or into stock.

There are several objections to this method.

It requires a large amount of manual labour; it is slow and it is costly.

Further, the weighing of the coal in such a small unit as a barrow load—a little over two cwts.—invites inaccuracy and is a constant cause of contention between the seller and the buyer.

This problem has been successfully dealt with in several ways.

An elevator has been lowered into the barge and the coal picked up and conveyed to the desired point, being weighed *en route*. This method is suitable for nuts or slack, but is not found to answer where the coal is irregular in size.

To deal with such material a jib crane and grab is found to be very effective.

The strong steel teeth bite into the cargo and firmly retains the mouthful until ordered to disgorge on to a breaker fixed over an automatic weighing machine, through which the coal passes into hoppers, and from which it can be taken as required for hand charging the retorts, or the weighing machine may discharge into the boot of an elevator and be conveyed to overhead hoppers from whence the coal may be drawn as required for machine stoking.

Or, if the distance between the barge and the retort house is too great for the swing of a jib crane, a transporter would be found more suitable.

Delivery of coal by canal is not so usual as delivery by rail, and this is more readily dealt with.

It is especially the case when the level of the railway line is much higher than the works, so that the coal can be tipped into breakers which discharge into the hoppers.

It may be noted, in passing, that in selecting a site for a gas works the question of levels is one of great importance, as is also the possibility of running a railway siding into the works. There is a gas works (Preston) where the conditions are perfect, as there is a railway siding at a high level and a canal at a low level, so that coal is passed from the wagons into the retorts by gravity and the coke discharged into barges by the same inexpensive power.

Such cases are, however, very exceptional, and the useful elevator and conveyor have to be arranged for.

Another way of solving this problem is to erect a wagon hoist and by hydraulic power lift the 20 tons to the level required. The outlay is a heavy one, but if there is full work for the plant it would be found a profitable investment.

The simplicity of working and low cost of maintenance strongly recommend the hydraulic hoist for acceptance.

Probably enough has been said about the conveyance of coal into

the retort house, and the next problem: "How best to turn the coal "into gas and coke" must now be considered.

It would be interesting to trace the progress made in the treatment of this question from the time when gas manufacture was in its infancy.

But we must not do more than briefly refer to the iron retorts designed by Murdock, Clegg, Accum, Malam and others, whose inventions frequently were more ingenious than practical.

With retorts vertical, inclined or horizontal, single or set in a group, cylindrical, D shaped or like an oven, the law of the survival of the fittest operated; fireclay displaced iron as a more suitable material for the retort, and the setting of a number of retorts in a bed heated by one furnace was accepted as the best method of carbonising coal, having regard to a large make of gas and a small expenditure of fuel.

Of course there were differences of opinion between engineers as to the number of retorts in a bed, the range from 3 to 10 with corresponding variations in the size of furnace and the arrangement of flues gave ample scope for discussion.

A new feature, however, appeared in the substitution of gaseous firing in place of the furnace.

Oechelhanser's Generator Furnace, followed by the Siemen Regenerators, showed such low figures for fuel consumption, that direct firing had to retire to a back position, whilst in addition to the saving in fuel there was the important advantage of the more uniform heating of the retorts and the perfect control of the heat afforded by the system of gaseous firing. It is not necessary to take up the time of this meeting by giving details of what must be familiar to those whom the author has the honour of addressing, but he will conclude this part of the subject by stating that it is yet an open question whether the producer should form part of the setting—whether it is best to have one or two producers for each bed, or one large producer distinct from the bench (which consists of a number of beds), and from which the fuel gas is conveyed to each bed.

It may be well now to consider the problem of charging the retorts with coal and withdrawing the residue—coke—after the gas has been driven off.

A very few words will describe the elementary method.

The retorts being at the right temperature and the coal (a weighed quantity called the "charge") having been deposited on the floor in front of the bench, the stoker opens the retort lid and dexterously shovels the material into its fiery bed, where it should lie in a thickness of about three inches, evenly spread over the bottom of the

retort. The lid is then replaced, when the gas flies along the ascension and dip pipes, and bubbles through the water seal of the hydraulic main. Or, in place of the shovel, the scoop is used. This is a trough of sheet iron rather longer than the retort and fitted with a T handle at the front. The charge is laid evenly in it, and three men (one at each side holding a bar and one holding the handle) lift it up to the level of the retort, slide it in, and then turn it over so that the charge is deposited in the retort, the scoop is then quickly withdrawn and the lid closed.

To withdraw the coke a long rake is used in a way that is obvious.

This method of hand labour has not given satisfaction. Too much time is taken in charging, with a consequent loss of gas from the open retort. Too much money is paid to the stoker, who is a highly paid individual; for while classed as an unskilled labourer, he has managed through union organization (strikes, &c.) to fix a comparatively high scale of wages.

In this age of mechanical contrivances and labour saving machinery, this problem has received much attention.

The pioneer gas engineers were not, however, indifferent to the subject.

Lee and Philips used a vertical retort, about 4 feet in diameter, and of rather greater depth, and in order to facilitate the discharge of the coke, an iron cage, formed somewhat like a grappler, was let down into the retort previous to the charge being put in, and when the process of distillation was completed, the grappler was lifted out by means of a small crane carrying the mass of coke with it.

Another cage being then introduced a fresh charge of coal was thrown in and the process repeated. This may be regarded as the first attempt at mechanical stoking.

Clegg's web retort, although not put in practical operation, was very ingenious. Coal was placed in a hopper, and passed by means of a star wheel on to a band consisting of linked metal plates, which was slowly passed through a horizontal retort, when the gas was driven off, and as it turned over a wheel at the end of the retort, the coke dropped off into a sealed chamber.

Mr. Brunton, of West Bromwich, in the year 1835, designed a retort which was fed from a hopper, and the charge on being pushed forward by the action of a piston, the rod of which worked through a stuffing box on the lid, discharged the coke into water at the opposite end. This invention was found to be practical and the plant was working for a considerable period.

Mr. Andrew Scott, of Musselburgh, was even more successful. He employed a conical retort placed in a vertical position. Its upper end was furnished with a hopper and valve, which enabled the charge to be readily and quickly introduced, and the bottom was set in a trough containing water, which acted as a seal to prevent the escape of gas while allowing the coke to be easily withdrawn.

Of course the retort was fixed in a brick setting, with the necessary furnace and flues.

The manner of working the retort was as follows:—The coal was deposited on a platform terminating in an inclined plane slightly above the level of the hopper top of the retort; the stoker shovelled sufficient coal into the hopper, and then depressing the valve by placing his foot on a lever, the coal dropped into the retort; on removing his foot a counterpoise weight brought the valve back into its seat, and closed the orifice. The coke was withdrawn from the trough by a rake or by means of a rocking shaft having projecting arms that pushed the coke out of the trough into the wagon placed to receive it.

The removal of coke from below, caused the contents of the retort to drop and make room for a corresponding addition of coal at the top, so that within the retort, distillation was being carried on in stages, and the flow of gas was steady and continuous.

Difficulties arose when caking coal was used, as that material became so enlarged and consolidated as to jam itself against the side of the retort and thus stopped the orderly downward movement necessary for the process. But with Scotch shales and cannel coal the results obtained were very satisfactory.

At later dates many other forms of coal charging and coke drawing machines were introduced to the gas world, but we must be content to mention the names of the inventors, as they possess only an historical interest.

Green, then of Bolton, now of Preston, 1860; Dunbar and Nicholson; Holden; Somerville and Robinson, who improved Holden's machine; W. Mann; W. Richards; Darlington and Scott, whose introduction of a screw to withdraw the coke was quite a novelty; Rowbottom (bulky and cumbrous); Warren and Wates.

The first machine, however, to establish itself as reliable and practical was the invention of Mr. Foulis, of Glasgow, and which, being improved by Sir Wm. Arrol, is extensively used and known as the Arrol-Foulis machine.

In this machinery a new departure was made in the motive power.

Steam had been used previously, but hydraulic power was now employed, no doubt owing to its general introduction as a motive power at that time.

The drawing and charging machines are each mounted on a separate frame, and traverse the floor on rails laid in front of the benches. Both are capable of adjustment to suit the levels of the different retorts.

The drawing machine consists of a malleable iron tube of a length corresponding to that of the retort. A piston and piston rod work in this tube. To the rod a drawing rake is firmly fixed. These appliances are supported on the frame, the tube being suspended in the centre on a double joint, so that it may be moved freely in every direction.

An equilibrium valve is attached to the frame, by operating which, water can be passed to either end of the tube.

On the spindle of this valve there is a pulley to which is attached a short chain, the other end of the chain being fixed to the end of the drawing tube. When the valve is turned to the proper position for sending the rake into the retort, the pulley turning with it draws down the end of the tube and elevates the rake so that it passes clear over the top of the coke.

When the valve is turned in the opposite direction so as to admit the water to the opposite end of the tube, the rake falls into or behind the coke, which is then drawn out. The whole is not drawn in one operation but by several movements.

The action is very similar to that performed in drawing the coke with a rake by hand.

It is not necessary to describe the pumping and other machinery by which water with 120 pounds pressure is provided and conveyed to the machines.

The charging machine consists of a cylinder carried on a frame with piston and piston rod. On the rod there are two pulleys, round which a flexible steel wire rope is passed, and also around pulleys on the end of the frame. The ends of the rope are passed half round the end of the barrel to which the pusher is attached.

Fixed on the frame is a hopper large enough to hold several charges of coal and from which each charge is dropped on to a trough.

The machine is placed in position and the trough by means of a hinged plate is made continuous with the retort.

A portion of the charge is dropped into the trough and then pushed along the retort to the extreme point by the "pusher," then

withdrawn and another portion dropped and pushed into position, and so on until the retort is charged.

Usually six movements complete the charge.

With "through" retorts, 20 feet long, two machines are used conjointly.

Another machine which has been extensively adopted was invented by John West, then of Maidstone, and now of West's Improvement Company, Manchester.

The motive power is air under pressure. The charger, as in the previous machine, is formed of a frame carrying a coal hopper and scoop (or charger) with the actuating machinery, and runs on rails laid down in front of the bench.

The "charger" consists of a scoop and carriage containing the mechanism for emptying the coal out of the scoop and righting it for a fresh supply. It is also arranged that the scoop shall enter the retort twice in order to make a complete charge, first turning over in one direction and next in the other, thus throwing the coal towards the right and left hand sides of the retort respectively.

The drawing machine consists of a rake having a slipper, which enables the rake to slide over the coke until it reaches the point of withdrawal, when it is turned over, and grasping the coke draws it to the mouth.

The rake rests on sheaves, which are attached to slides suspended from a chain passing over a pulley to a drum which is attached to the front of the frame and turned by a worm and wheel.

It is claimed that West's machinery does the work at a lower cost than the Arrol-Foulis, but the author has only practical knowledge of the latter.

There is no doubt that with each machine the cost of carbonising is much cheaper than with hand labour, but when all the items of cost are put together, viz. :—

(*a*) Interest on the Installation, viz. :—The machines and the plant required to furnish motive power—either hydraulic or pneumatic power.

(*b*) Cost of maintenance, which is heavy.

(*c*) Wages paid to men working the plant and machines—the margin of saving has not been found a large one.

It is not surprising, therefore, to find that other drawing and charging machines have been brought into existence.

Two of these—the Paris Turbine, and the De Brouwer—are worthy of notice.

In each machine, electricity is the motive power employed, and it

certainly possesses advantages over steam, hydraulic, and pnuematic power. The cost of the generating plant is much lower, and its application to the machines much more convenient and inexpensive.

THE PARIS TURBINE.

The charging machine is carried by a frame mounted on wheels, and runs on rails in front of the retort bench.

The coal is broken to a suitable size and placed in a hopper carried by the frame. Below the hopper is a turbine so placed that the charge of coal falling from the hopper is whirled out through a shoot and deposited in the retort. The speed of the turbine is gradually reduced and thus the throw of the coal is diminished, so that whilst the first portion of the charge reaches the far end of the retort (say) 20 feet in length, the final portion is dropped close to the mouth.

The action of this machine very closely follows that of the man with a spade.

The coke discharger, however, unlike all previous machines which copied the movements of a man with a rake, boldly pushes the coke out of the retort. The pusher consists of a rod with a plate at its extremity, carried by a tube, on the telescope principle, which is propelled against the coke by a chain and pulley arrangement, the motive power being that of electricity.

These machines have been in operation for some time at La Villette Gas Works, Paris ; and more recently at the Gas Light and Coke Company's Works, Beckton, London.

THE DE BROUWER.

Machines, invented by an engineer of that name, of Bruges, have electricity for their motive power also. The charger, as in the machine last described, throws the coal into the retort, but the impulse is given by a rapidly driven band on to which the coal is dropped from a hopper, and in this case the speed is also reduced so as to deposit the coal evenly between the extreme end of the retort and the near mouthpiece.

The idea is ingenious and the mode of operation a very simple one.

This machine is less expensive than the turbine and is said to be more reliable.

The coke discharger, whilst differing in design to the Paris machine, works on the same lines and need not be further described.

In addition to the installation at Bruges, there are several at work on the Continent and in this country. The Gas Committee at Derby acquired the machines and have been using them for more than a

year; it is said that they give great satisfaction and that the cost of carbonising has been reduced to a very low figure.

At several other gas works, installations are either at work or being laid down.

INCLINED RETORTS.

The problem of charging and discharging retorts has been dealt with in an entirely different manner by the inclined retort system; this may be taken as a method of minimising machinery and avoiding the heavy cost of wear and tear involved thereby.

As previously stated, the gas world had settled down to the use of horizontal retorts, but a radical change was made at Rheims, where a bench was erected in which the retorts were placed at an angle of about 30 degrees, the charge of coal being admitted at the top end and the coke being emitted at the bottom.

The credit of being the first English gas undertaking to adopt inclined retorts (called "slopers" for brevity) must be given to our enterprising neighbours at Birkenhead, for although the installation was not successful and had to be abandoned, the idea was a good one, and (after the lessons of experience had been learnt) has been successfully worked out in many places.

The following is a brief description of a sloper bench. The coal is passed through a breaker and made uniform in size, elevated and conveyed into fixed hoppers situated above the bench.

From these the charges of coal are taken in charging machines that run on rails suspended in front of the bench, so as to enable each to be placed exactly at the mouth of the empty retort.

By simply moving a lever, the stoker allows a stream of coal (a measured charge) to run down the sloping surface of the retort, its progress, however, is blocked by a frame that is placed across the retort near the lower extremity, known as the "stop." The head of the stream thus blocked, instantly arrests the material that was following it, which in turn affects the next portion, so that in a few seconds the sloping surface is covered with a uniform thickness of coal, about three inches, extending from the "stop" to the charging end. The "charger" is then moved out of the way, the lid closed and the process of gasmaking goes on, the gas being conveyed away by ascension pipes fixed at the lower end of the retort.

At the end of the allotted time for working off the charge, the lids at each end are opened. The "stop" is quickly removed and instantly a stream of coke descends, and passing through an opening in the floor is caught by the wagons that await it in the cellar below.

The retort is then ready for another charge, the "stop" is replaced and the process repeated.

It must be understood that the retorts are set in a bed, in settings of six, eight, or other convenient number, and are uniformly heated by fuel gas generated in a producer, as previously referred to.

Too great importance cannot be attached to the sufficiency and uniformity of the heating of the retorts. Unless the whole of the gas is driven off, the coke will stick together and will not flow out of the retort.

If through insufficient heat in any part the charge cakes together and men have to be employed to poke it down from the top and rake it from below, the saving in cost quickly melts away.

It is most important, also, that the setting, viz., the arrangement of brick and tiles that forms the combustion chamber and flues, which carries the retorts, should be made of material to stand the heat and also the strains set up by the expanding effect of the intense heat employed; and, further, that the whole bench should be properly supported and braced.

At the present time, while all gas engineers are agreed that hand work is costly and inconvenient and should be abandoned in respect to a large proportion of their plant, there are differences of opinion as to the system to be substituted.

Probably there are local circumstances that favour one system rather than another, and possibly some engineers have been more fortunate in their operations with one system than with another.

In respect to the electrically driven machines—Turbine and De Brouwer—and also the slopers, there has not yet been sufficient time to answer the question of durability, but a keen interest is being taken in this and the many other problems of a gas works, so as to enable gas to maintain its pre-eminent position for the supply of light, heat and power.

In concluding this attempt to put his brother engineers in touch with some of the problems that are engaging attention in his branch of the profession, the author would conclude by saying, that in science and art there is no finality—that to the engineer there are always new heights to climb—every ridge gained but reveals higher ground beyond, to gain which, calls for fresh efforts and strenuous application; and, when gained, merits (if it does not always receive) the laurel crown.

DISCUSSION.

Mr. Thomas L. Miller said—I had hoped that some member of the Society more particularly interested in gas engineering would have come forward to open the discussion, as, personally, I cannot claim to have an experience of gas works' engineering. Mr. Miller

The point in the paper to which I should like to draw particular attention is that on page 19 where the author deals with a point which should, I think, form the basis of all engineering work, and that is the question as to whether the improved machinery or apparatus which we propose to introduce will pay. This, unfortunately, is a point which, I think, is often lost sight of, as I am sure examples will readily occur to the minds of many members of cases where plant and apparatus have been installed which would never have been put in, had the saving to be effected by the adoption of such plant and apparatus been compared with its upkeep and the interest and sinking fund on the capital cost incurred by its adoption.

It is, as the author points out, no use putting down a plant, no matter how beautiful the plant may be from a mechanical point of view, unless its adoption is going to pay.

I do not propose discussing the paper, as my experience in gas works' engineering is so very limited that I fear any remarks of mine on the paper will be of little value. I should, however, like to point out that while the author has entitled the paper, "Some Engineering Problems in Gas Works," he has only touched the problems met with in the retort house, and has left untouched many more problems of a most interesting nature which, personally, I should have been pleased if he had dealt with.

In the last paragraph but one the author refers to the "many other "problems of a gas works, so as to enable gas to maintain its pre-"eminent position for the supply of light, heat and power." In going through gas works, however, one usually finds that while gas engineers, *outside their works*, draw particular attention to what they term "its pre-eminent position for the supply of power," and strongly recommend the use of gas engines, it is frequently found that *inside the works* the steam engine is adopted, where to an outsider it would appear that the more modern gas engine might have been expected to be used.

Mr. Miller Possibly this may be due to other considerations, but as an electrical engineer it has frequently occurred to me that if the motive power were only concentrated at one point and the energy distributed by means of electricity, a much more convenient arrangement than that existing in most gas works might result.

Col. Holme Colonel A. H. HOLME said—I do not know very much about gas-making, but there is one thing which has struck me—I am perhaps wandering from the subject—and that is, how is it that gas companies have never attempted to supply electricity themselves by making a cheap gas and putting down gas engines and dynamos at their works? It has always struck me as a very remarkable thing that something of the sort has never been attempted by the gas companies, and I should like to ask the author if the idea has ever occurred to him and if there is any reason why it should not be done.

Mr. Carr Mr. ISAAC CARR said—I have listened with very great pleasure to the paper. The author explained to me before the meeting that this is a paper not written specially for gas engineers but rather for a general body of engineers such as this, and therefore the paper partakes more of a descriptive character of gas engineering plant than anything else.

It is a matter of great contention amongst gas engineers as to what is the most economical method of applying machinery to the various manufacturing operations. The great difficulty, to my mind, in applying machinery, has been the fact that in gas works very high temperatures have to be dealt with which do not obtain generally in other manufacturing operations. Steel and cast-iron will do wonderful things at a normal temperature, but when high temperatures (say) equal to a dull red heat are reached, they become weak and useless, and as a result of this many of the machines that have been invented prove, when they come to stand the test of actual gas stoking, to be in many respects wanting.

The De Brouwer machine mentioned by the author is a distinct departure from the ordinary kind of retort charging machine, inasmuch as there is no actual contact in the charging operation with the retort, and it would appear that the De Brouwer machine will meet with a greater measure of success than anything hitherto tried in consequence of this.

The author speaks of the mechanical operations in discharging. Of course, in writing this paper, his ideas would, no doubt, be formed, in a great measure, by his own operations, which we all know are on a

very large scale, but in the smaller gas works the consideration of these problems takes a very different aspect, and a great deal can still be done in smaller operations by the old-fashioned methods where the use of machinery has been found to be unprofitable. Mr. Carr

Again, referring to the difficulty of dealing with machinery and retorts, I may say that years ago I had occasion to work West's machine, and to give you some idea of the destruction that can take place owing to a little carelessness on the part of the man in charge, I have known the charger to go in the mouthpiece, to stick fast, and before it could be got out practically melted, the retorts had to be broken out and it has gone down through the bottom of the retort and been brought out finally through the furnace door at a temperature of 2,000 degrees Fah.

I think I was the individual who was accused by the author of smiling audibly when he referred to the sliding coke from the inclined retort, but amongst gas engineers it is well known that there is very great difficulty in getting the ideal operations in practice and I need not dwell upon this, but those gentlemen who know something of gas engineering know the difficulty of getting inclined charges to run down.

The author's reference to the ideal position of the gas works at Preston strikes me as being somewhat peculiar when considered from the point of view of results.

It is said that the works are on a hillside possessing the natural advantages of the coal coming in by rail at the top and practically falling by gravity to coal stores and retorts and finally the coke into canal barges at the bottom. If this ideal position of a site is suggested by the author, as a matter of commercial utility in the process of gas manufacture, one naturally looks to the selling price of gas in Preston for a reflection of the advantages.

The price of gas in Preston is, however—having regard to the size and locality of the works—as high as any in England, so that one may wonder what the fate of the consumers would have been in the matter of price had not a beneficent providence blessed them in the manner alluded to.

Just one word as to the progress which has been made during my 20 years' experience, from a lighting point of view. This is rather departing from the subject, but it is interesting when we hear people inclined to argue that gas, as a lighting power, is fast disappearing. Twenty years ago the best result that could be obtained from gas was four-candle power per cubic foot—that of course with ordinary

Mr. Carr burners. Now, with the intensifying incandescent light, that candle power has been increased to quite 40. Improvements still keep being made, and, so far, there appears to be no finality as to the duty that can be obtained from gas with the special application of pressure and the incandescent burner.

Mr. Tagg Mr. S. Tagg said—The paper has been a pleasure to listen to, but in so far as the author has made it of interest to the general body of engineers present, he has, to a certain extent, precluded the gas engineers from taking a particular interest in it.

I should have been glad if the author had been a little more committal in his paper; if, from the benefit of his very wide experience, he had given a definite opinion on certain debatable points raised. It is not given to every engineer to have more than one carbonising system in operation where comparative results can be obtained, and the author's conclusions would, therefore, have been of special interest.

The first point I should like to mention is with regard to the importance of seeing that any proposed capital expenditure should return a satisfactory revenue. There is a still further point that I think is well worth noting, and that is, that even whilst the capital expenditure may return a satisfactory revenue compared with manual labour at the present time, it might be unwise to risk a large amount in view of any possible improvement or substitution of other forms of machinery and plant. It is very necessary, therefore, that there should be a considerable reserve of profit as a result of the introduction of machinery.

In reference to the introduction of stoking machinery the author says that the economy effected has often not been very great. I think the responsibility of this very often lies at the door of the gas engineer himself. Capital has been spent and machinery introduced, and the engineer possibly ceases to take that active interest which ensures the satisfactory working of the plant. The plant has ceased to be a novelty, and as time goes on labour is put on which it cannot bear. It needs strict watching to ensure no labour being saddled on any machinery except what is absolute necessary.

Another fact tending to decrease the efficiency of the machinery is, that the operations of gas-making are continuous for twenty-four hours, and there are of necessity certain portions of the day when the engineer is not present and when the same care is not exercised by the workmen.

I do not know whether I am trespassing on the author's right

of reply, but reference has been made to the general use of the steam engine to the exclusion of the gas engine in gas works. I should like to say that gas works are placed in an exceptional position for the production of steam, as they have a surplus quantity of coke at their doors, and steam is also used for many other purposes than motive power in works. Mr. Tagg

It may be interesting to note that much misconception exists as to the relative positions of the gas and electric lighting industries. The common idea is that gas is being displaced very rapidly. I rather think it has benefited by the competition; the general standard of illumination is being increased, and the relative figures in my mind, as applied to Birkenhead are, that the consumption of gas is some 30 times greater than the equivalent consumption of electric current.

Since the introduction of electric light the output of gas has grown to the extent of about 50 per cent. which, I think, indicates that we are not merely holding our own.

In reply to Mr. Miller's question, the output of electricity was inclusive of light and power, but exclusive of tramways.

Mr. Thomas Duncanson said—Gas engineering is one of the branches of engineering which is very much specialised, and the author must have had some difficulty in writing so that he could cater for the general engineer, while at the same time providing matter interesting to the specialist. Mr. Duncanson

I should like to ask the author, if, looking at the question from the point of view of the consumer, he could explain to us what gain is likely to accrue from the improvements that have been described in the methods of charging, &c. From this point of view I would like to have some idea of how much per 1,000 cubic feet the total labour costs for charging run to at present and what amount of saving might possibly be made by the improved appliances.

Mr. W. E. Mills said—There is one question which I should like to ask the author, and I hope he will forgive me if it sounds very elementary to him. I have noticed one point which it has occurred to me that engineers might have directed their attention to with advantage in the way of improvement, and it is this—I speak, of course, of the ordinary way of charging as described in the paper—by shovel and barrow. It always seemed to me that when the retort lid was opened and the charge thrown into the retort, there was an appreciable interval of time during which the coal burnt and did not carbonize but simply ran out into flames, and I rather expected that in the paper to-night we might have heard of some Mr. Mills

Mr. Mills ingenious engineer directing his attention towards the minimising of this loss. When you come to have a large number of retorts at work and each one charged a great number of times, the loss might come out to be considerable. I do not know whether any means are taken to prevent the escape I speak of, but if so, I should be interested to know what they are.

Then, again, I was very much interested in the description of the failure of the installation of inclined retorts at Birkenhead. I had an impression some years ago that the system of charging retorts adopted there was an extremely good and workmanlike idea, but the author says that the system was a failure, though it has since worked successfully in other places, and I should be glad to know whether it has really achieved success, and where.

I think one of the speakers mentioned certain difficulties which had arisen in the use of inclined retorts, and I think I gathered from him that occasionally the charge had to be raked out, and of course it is quite possible that what in theory appears to be a perfectly simple proceeding does not work satisfactorily in actual practice.

Mr. Kershaw Mr. J. B. C. KERSHAW said—Before the author replies I should like to ask one question. Some three years ago I saw it stated in print that one of the South Lancashire towns was being supplied by the local gas works with gas at 1s. 6d. per 1,000 cubic feet for heating purposes. I desire to ask if that price has yet been improved upon by any gas plant in the country, and also to enquire if there is any hope of getting down to 1s. per 1,000 cubic feet for large consumers.

Gas retorts are certainly rather old-fashioned and out-of-date for the production of gas from coal, and I should have thought gas engineers would have been seeking improvements along the line of continuous charging and production rather than in any mechanical methods of charging fuel into the old intermittent retorts. Perhaps the author will inform me whether any attempt to use revolving furnaces or retorts, with continuous feed of fuel and discharge of coke, have yet been made in the gas industry. Such types of furnace are well known in the chemical and cement industries, and it is, one would think, only a question of design to render them suitable for gas-making. Their introduction would certainly lead to great economies in costs of labour for a large gas works.

Mr. Allen Mr. ALLEN, in reply, said—I am glad now to have the opportunity of expressing my own dissatisfaction with the paper. When your President was good enough to invite me to contribute a paper, he may remember that it was with considerable hesitation I consented to do

so. I felt that the time at my disposal was so short, and that this Society deserved a paper that would represent a greater amount of care than I could afford to give to it. But he was good enough to say that the members of the Society would like to have a paper on Gas and that it might be a matter of interest to them. Mr. Allen

I am very much obliged to the gentlemen who have spoken for the kind way in which they have treated the paper. It may not be worth very much, but the discussion it has raised has been of great interest.

Mr. Miller's remarks as to the financial side of the introduction of improvements echoed the views of the President of the Institution of Electrical Engineers at the meeting in London last week, when he made a very great point of economical production in manufactures.

Mr. Carr brought up the same point as being a most important one. He is a gentleman who has tried with success to make gas very cheaply. I do not want to enter into a comparison between low quality and low-priced gas as against high-priced and high quality gas this evening, and I am sure Mr. Kershaw will excuse my not answering his question. Local circumstances settle that point. A gas company, like other tradesmen, supply the article that is best suited for the requirements of its customers.

With regard to the many problems not dealt with; my original intention was to run right through a gas works. But when I came to write the paper I found I could not get away from the retort house. I may, however, have an opportunity of supplementing the paper on some future occasion.

The ex-President referred to the absence of gas engines in gas works, but Mr. Tagg has dealt with that point. If use is made of refuse coke, steam can be raised very cheaply, but for power purposes there are many gas works in which are found good installations of gas engines. It is a very convenient power, as the machinery takes up very little space. Electrical power is being very much appreciated and it can be put into even smaller space. If the Paris Turbine or De Brouwer's machines come into general use, electrical power will have to be generated on gas works.

With regard to Col. Holme's remarks about the indifference of gas companies in respect of the manufacture of electricity, it must be explained that gas companies, under their Acts of Parliament, are confined to the manufacture and distribution of gas. If they desired to take up the manufacture of electricity it would be necessary to obtain special powers. But as a rule you will not find that a gas company has much spare space in their works.

Mr. Allen They require it all to deal with the particular business in which they are engaged.

The remarks as to the paper not being of particular interest to gas engineers is, I think, so far as it goes, a compliment. I did not expect to have a large number of gas engineers present, and if they had been particularly interested, the others would not have been. I have simply tried to bring the members into touch with some of the problems we are dealing with day by day.

The improved duty of gas during the last 20 years, referred to by Mr. Carr, is undoubtedly due to the competition we have had to do with. We are not disposed to give way, and whilst there is great activity on the part of the attacking body, the defending body is by no means idle.

It is quite true that in many works machines have been carefully constructed and left working perfectly, but afterwards they have been neglected by those in charge, and therefore failed to give satisfaction.

I think the moral is, that our young men should be technically trained and thus be able to take an interest in the machines that will enable us to reduce the cost of manufacture.

Mr. Duncanson asked a question as to what saving might be effected per 1,000 cubic feet by the use of special machines. I will give you a figure—between hand labour in the retort house and an inclined system there is a difference of about 1s. 4d. per ton. Divide that by eleven and it brings you very nearly to 1½d per 1,000 feet, which is a substantial reduction.

Mr. Mills spoke of the loss of gas when the retort lid was opened. One of the earlier machines that I described was intended to deal with that difficulty. That particular plant was in use for many years in Scotland, and at the present time gas engineers are working on the same lines. The Settle-Padfield retort and the plant at Mariendorf are giving encouraging results.

There is no doubt that the principle of the vertical producer is right. It enables the process of gas-making to be continuous, and avoids the loss of heat and of gas, involved by the use of retorts.

The "inclined" bench has improved very much since the day when it was tried and failed, and is now working successfully in many towns. The installations in Liverpool have given great satisfaction, and as opportunity offers other benches will be erected.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

THIRD MEETING—30TH NOVEMBER, 1904.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

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NOTES ON SOME HYDRAULIC LIMES.

BY S. H. ELLIS, Assoc. M. Inst. C.E.

THE subject of Hydraulic Limes is one that has received, of late years, comparatively little attention from English engineers. In the paper on "The Fisher Tarn Works," read before the Liverpool Engineering Society by Mr. Parkin, in January, 1903, some description was given of the properties and methods of using of a hydraulic lime made from a limestone of the Lias formation. During the discussion several speakers referred to that part of the paper; and it seemed to the author that it might be of interest to follow up the subject somewhat farther, more especially with reference to the use of hydraulic limes on the Continent, where they have been used more widely than in England, and where for certain classes of work they successfully compete with the employment of Portland Cement.

For many years researches have been made by scientists—M. Vicat, Le Chatelier, Candlot, and others—for the purposes of ascertaining the composition of these limes, and the methods of manufacture and use best suited to different conditions. The result is that natural hydraulic limes are available for use by French and German engineers with much of the certainty that attaches to the employment of Portland Cement in England. The author has had the opportunity to become practically acquainted with one of these limes, that of Teil, and was impressed with the advantages that might accrue if some such source of supply were available nearer home.

One can well understand the reluctance of English engineers to order the use of hydraulic lime for a large work in concrete—dock walls for instance—in preference to Portland cement. The properties of the latter are well known; there is a standard specification for its use; one merely has to order from a good maker, and make a few simple tests, to be free from all further anxiety on the subject. Hydraulic limes, on the other hand, are in the first place natural products, and depend for their reliability not only on the care bestowed on their manufacture and use, but also on the composition and homogeneity of the stratum which supplies the limestone. And it is here that the chief difficulty arises.

English hydraulic limes are usually prepared from limestones of the Liassic series. As is the case with all strata of the Secondary formation (which are of sedimentary origin) these beds vary considerably in character according to their position in the series, as well as with the particular locality in which they are found. The Upper Lias beds, for instance, are liable to approach in composition to the Oolitic limestones which come immediately above them; while the Lower Lias usually partake somewhat of the nature of the marls of the Upper Trias. The former would yield a lime of poor hydraulic qualities, the latter a lime eminently hydraulic, but with a tendency to unevenness of composition. Great care is thus required in selection and constant inspection of the strata from which the limestone is quarried, if a product of any homogeneity is to be obtained.

The term hydraulic lime is in itself somewhat vague; and to attempt a definition it is necessary to go briefly into the composition of calcareous products in general.

In the first place, quicklime, or calcium oxide (CaO), is obtained by heating to redness a carbonate of lime ($CaCo_3$), and by this means expelling the carbonic acid gas (CO_2), which is driven off in the form of vapour. If a pure form of carbonate, such as chalk or certain

limestones, be selected as the material, the resulting product is pure quicklime, which, on contact with water, becomes completely hydrated, or slaked, forming calcic hydrate (CaH_2O_2), in the form of powder. Great heat is evolved in the process, and the volume of the lime is increased by over one-third. Such a lime is termed "fat" or "rich," and if immersed in water has no power of setting. If mixed into a paste with sand, the resultant mortar dries to a firm consistency in air, and is frequently used as a binding material for ordinary building. It has, however, no real power of setting, except superficially in the course of years by re-absorption of carbonic acid gas from the atmosphere.

Fortunately the majority of limestones contain, besides calcium carbonate, varying percentages of other minerals, chief among which is silicate of alumina (common clay), with varying chemical formulæ of which ($Al_2O_3 2SiO_2 + 2H_2O$) may be taken as a standard. The presence of clay in the limestone has a marked action on the behaviour of the lime, varying directly with the percentage contained, but always lessening the tendency to slake to a powder and expand in volume when treated with water, and imparting the quality of setting in air, and to some extent under water. These properties are usually termed hydraulic.

Thus, a limestone containing from 8 to 12 per cent. of clay with magnesia and the oxides of iron and manganese is said to yield a feebly hydraulic lime; one containing 15 to 18 per cent. of these ingredients yields a moderately hydraulic lime, which slakes with difficulty, and sets well in damp situations; while limestones in which over 20 per cent. of the above constituents are present yield eminently hydraulic limes, ranging up to cements, which, after calcination and grinding, are capable of setting in contact with water without perceptible change of volume or any notable evolution of heat.

The chemical re-actions attending the burning of these impure limestones are somewhat obscure; but it appears that, partly during this process and partly in the subsequent hydration, some of the lime enters into chemical combinations with the silica and alumina, forming stable and insoluble compounds. Silica is apparently the most valuable constituent if in a state to enter into combination. When in a crystalline form, as grains of quartz, it is insoluble and consequently inert; but when in a nascent condition (*i.e.*, just released from a chemical combination, as with the alumina of clay), it combines readily with the lime. More rarely silica is present in a limestone in a pure but soluble condition, as minute particles, and then affords the

possibility of obtaining a lime of valuable hydraulic qualities, but which burns more evenly and slakes more perfectly than one containing a large percentage of alumina.

One of the best known of English hydraulic limes is that manufactured at Barrow-on-Soar, in Leicestershire. It is made from limestone of the Lower Lias beds, which on the quarry-face present the familiar appearance of a blue-grey rock streaked with veins of brown. The beds are not homogeneous; but their character is so far denoted by their appearance and position that the manufacturers claim to be able to blend the different varieties of stone together, and to obtain lime of two classes which are each of practically uniform quality and composition.

The first of these, which may be classed as of moderately hydraulic properties, is termed lump lime, and is burnt from stone containing about 80 per cent. of carbonate of lime. The raw material is put into the kilns in layers of about a foot thick, between each of which is a layer of coal slack. When a kiln is charged and lighted no more material is added, the contents burning through from the bottom, and the lime being extracted when the operation is completed. The lime is obtained in lumps, in which state, without undergoing any further process, it is sent out on to works, to be there slaked and screened by the users.

The second of the Barrow products, termed ground lime, is burnt from limestone containing a larger proportion of silica and alumina, and is eminently hydraulic. It is burnt in the same manner as the lump lime; but after extraction from the kilns the lumps are ground by millstones into a fine powder, which is loaded directly into sacks for delivery on to works. It keeps fairly well if stored in a dry place; but the mouths of the bags must be left untied in order that the bags may not be burst by the swelling due to gradual hydration of the lime.

It seems, indeed, to the author, that there is a decided element of risk in using this unslaked ground lime for either mortar or concrete without first shooting and turning it so as to obtain at least a complete air-slaking of all the particles.

The Barrow limes may be taken as typical of the products of that outcrop of the Blue Lias limestone which extends in a north-easterly direction across the centre of England, and which is quarried at a number of places between, and including, Watchett in Somerset, Barnstone near Nottingham, and Kirton-in-Lindsay in Yorkshire.

Barnstone hydraulic lime, for instance, which has a somewhat lower

commercial value than that of Barrow, has practically the same method of manufacture, and is similarly classed into lump and ground lime. The analysis of the latter is as follows :—

ANALYSIS OF BARNSTONE GROUND LIME.

Lime	59·64
Silica	20·60
Alumina	6·96
Oxide of Iron	4·01
Magnesia	2·25
Sulphuric Acid	1·94
Carbonic Acid	0·46
Water and Alkalies	4·14
	100·00

The lump lime has been largely used as a component of mortar for brickwork and masonry on recent extensions of the Midland Railway. The usual practice is to make the mortar in the proportions of 1 part of lime (slaked and screened) to 1 part of gritstone sand and 1 part of ashes, the whole being mixed in a mortar-mill to a stiff paste. This mortar gives excellent results, setting well in damp situations, such as the lining of a tunnel through shale, of which the Disley Tunnel, on the New Mills and Cheadle Loop Line, is an example.

All the Lias limes are frequently used in much smaller proportions, —1 to 3 or 1 to 4; and no doubt make a mortar sufficiently strong for ordinary building purposes. In a book published as early as 1836 the author, General Pasley, said that from repeated experiments made at Chatham, they found that Blue Lias lime mortar could not be made weaker than 1 to 2 without deterioration. The concensus of modern opinion would probably fix 1 to 3 as the limiting proportion for engineering works.

Another English hydraulic lime, that of Aberthaw, in South Wales, is of interest as having been used by Smeaton in the construction of the Eddystone Lighthouse, in 1856-9. Smeaton examined most of the English limes then known, with a view to obtaining one which would withstand the action of the sea, and afterwards published the conclusions he arrived at in his work on the Eddystone Lighthouse. The term "hydraulic lime" is here used for perhaps the first time; and it is interesting to note that while commending the natural limes of Barrow-on-Soar and of Aberthaw, he came to the conclusion that to obtain a mortar capable of actually setting under water it was

necessary to employ a cement containing a larger percentage of clay or oxide of iron than could be burnt from any limestone then known. Smeaton overcame this difficulty by using for mortar in the Eddystone Lighthouse a mechanical mixture of Aberthaw lime and puzzolana from Civita Vecchia, near Rome ; a device which is still constantly employed in Italy and Egypt with considerable success, puzzolana being a volcanic product consisting chiefly of silica and alumina, with a little lime, magnesia and oxide of iron.

Smeaton just failed to recognise what Vicat shortly afterwards discovered, that a truly hydraulic cement could be made by a mixture of limestone and clay before burning.

Aberthaw lime, like those previously mentioned, is obtained from the Lias formation, which is here exposed in the cliffs of Pleasant Harbour, on the north side of the Bristol Channel. The material actually used in the manufacture of the lime is obtained, not from the limestone stratum *in situ*, but from the pebbles which form the beach, these being ground by the action of the tide from the rock of the cliffs and harbour bottom, and thrown up on the beach in an apparently inexhaustible supply. The layers of shale and nodules of clay which occur in all the Lias beds are thus entirely eliminated; and the composition of the raw material is much more nearly constant than would be otherwise possible. The products of these works are classed commercially as lump and ground lime, the manufacture of each differing but slightly from those of Barrow. The ground lime gives the following analysis :—

Analysis of Aberthaw Ground Lime.

Lime	71·02
Silica	19·14
Insoluble Silica	2·38
Alumina and Oxide of Iron	3·64
Magnesia	0·94
Sulphuric Acid	0·69
Carbonic Acid and Water	2·22
	100·03

Aberthaw lump lime has recently been used by Mr. G. F. Deacon, M. Inst. C.E., in the construction of a concrete and masonry dam for the Upper Neuadd Reservoir of the Merthyr Waterworks. This is the second dam constructed in this country in which the cementing material has been mainly hydraulic lime—the first being the Fisher

Tarn Dam (which we have had described to us)—and in both cases entire success has been attained.

The method of dealing with the Aberthaw lime at the Merthyr works was much the same as that adopted at Fisher Tarn. The proportions of the concrete were 4 parts of broken limestone to $1\frac{3}{4}$ of mortar composed of $2\frac{1}{2}$ parts of crushed limestone sand to 1 of slaked lime, the stone being crushed to pass a $2\frac{1}{2}$-inch ring, the sand screened through a $\frac{3}{16}$-inch mesh sieve. The lump lime was brought in covered wagons to the mixing shed, slaked in batches and passed through a hopper to a burr-stone mill on the floor below, where it was ground, with the addition of water. to the consistency of a thick cream. This was measured with sand into a bladed mortar mixer, and afterwards made into concrete by the addition of the correct proportion of broken stone.

Extremely good results were obtained from tensile tests of $2\frac{1}{2}$ to 1 mortar briquettes, as will be seen from the following figures, which are the mean of a number of tests made on the works by Mr. T. F. Harvey, Assoc. M. Inst. C.E., the Resident Engineer :—

TENSION TESTS OF ABERTHAW LIME MORTAR BRIQUETTES.†

$2\frac{1}{2}$ ROCK SAND TO 1 SLAKED LIME.

Age in Months of Briquette when Tested				Fineness of Sand Screen	Remarks
2	6	12	24		
60	193	297	438	$\frac{3}{16}$-inch	Made from Slurry from Burr Mills
116	330	400	—	$\frac{3}{16}$ "	Suitable consistency
264	415	563	—	$\frac{1}{8}$ "	Do. do.
184	361	—	—	$\frac{3}{16}$ "	Lime screened through 2500 Sieve instead of ground

Such results as these are a sufficient answer to the remarks of Mr. Colson and Mr. Grant, in 1879, that Portland cement mortar, even of the proportions of 5 or 6 to 1, is stronger than any Lias lime mortar.*

* Minutes of Proc. of Inst. C.E., Vol. LXII.

† Proc. of Assoc. of Municipal and County Engineers, Vol. XXVI.

In referring to the Merthyr Works Mr. Deacon observed: "With "regard to the use of hydraulic lime as distinguished from Portland "cement, I have to point out one property which has not yet been "mentioned, viz., that the permanent elasticity of hydraulic lime "concrete and mortar appears to be greater than that of Portland "cement concrete and mortar. That property is of more importance "than strength in works of this kind." And again, mentioning the fact that the use of Portland cement has been the exception rather than the rule in the construction of high masonry dams, Mr. Deacon says: "In saying this, I say nothing against the use of that most excellent "material (Portland cement); but it is not necessarily better than "properly treated hydraulic lime, except where running water is liable "to be met with during construction, or where great stresses are to be "resisted very shortly after construction."

In comparison with these English hydraulic limes it is instructive to note the origin and properties of some which are in use on the Continent, and the author proposes to describe somewhat fully one known as Teil lime, which, being largely exported, is liable to come under the notice of English Engineers.

Teil lime is manufactured by the Société Pavin de Lafarge at their works at Lafarge and Teil, near Marseilles. This company is fortunate in having at their disposal a stratum of limestone (belonging to the Neocomian beds of the lower Cretaceous Formation,) which is well adapted for producing a lime eminently hydraulic in character and of an even composition. The analysis of the lime (which is of one class only) is given below, and is compared with that of some other Continental products:—

Composition of Hydraulic Limes of	Teil (Marseilles)	Tournay (Belgium)	Argenteuil (Seine)	St. Antonin (Garonne)
Lime	65·0	61·85	56·8	62·8
Silica	23·3	19·75	17·85	12·65
Alumina	1·2	3·44	5·2	5·3
Magnesia	1·2	0·66	1·35	2·3
Peroxide of Iron ...	1·0	1·16	2·4	2·35
Sulphuric Acid ...	traces	0·45	1·3	0·8
Lost in Burning ...	8·3	12·35	14·9	16·45

It will be noticed how nearly the composition of Teil lime approaches to that of a good English Portland cement, the chief difference being

that a large proportion of the silicate of alumina necessarily present in an artificial cement is replaced by pure soluble silica. This is an undoubted advantage for a natural product, as ensuring greater evenness of burning, and a freedom from clay nodules. Some chemists, indeed, assert that alumina is of no value except to release silica in a nascent condition.

Magnesia, also, is present in very small quantities; and for this reason Teil lime is generally used by French engineers for works in the Mediterranean, in preference to Portland cements of Continental production. These usually contain from 5 to 6 per cent. of magnesia; and are thus peculiarily liable to be attacked and decomposed by the waters of the Mediterranean, which are rich in salts. Teil lime is, like all hydraulic limes, unfitted to be laid under water, or in situations where it is liable to be covered by water soon after gauging; and the usual practice is to make concrete blocks which are allowed to set in air for a month or more before being built or lowered into place.

In the discussion on Mr. Grant's paper on Portland Cement in the Min. Pro. Inst. C.E. (Vol. LXII), a note is published on the use of Teil lime in the construction of Trieste Harbour. Blocks of rubble masonry, each having a content of about 350 cubic feet, were built up with $2\frac{3}{4}$ to 1 lime mortar, allowed to harden in the air for three months, and then built into the work. After twelve years, alterations in the scheme of the works necessitated about 4,000 of these blocks being raised again by divers. Of this number a proportion of 91·3 per cent. were in good repair, 6·2 per cent. repairable, and 2·5 per cent. beyond repair. Among those which had remained sound were some which had been immersed to a depth of 40 feet below water, and others which had been subjected to enormous strains through the unequal settlement of the wall of which they formed a part. Of those which were broken, the fracture had in most cases taken place through the embedded stones, showing the strength of the matrix.

It is not at all certain that Teil and other hydraulic limes can be as safely used in a tidal ocean as in tideless seas like the Mediterranean. Practical experience in this direction is to a great extent wanting; but some lengthy experiments made at Rochelle, by M. Coustolle, show that lime concrete blocks subjected to alternate immersion and drying tend to decompose to some extent in course of time, apparently owing to the comparatively greater permeability of lime mortar. It has also been pointed out by M. Equer, in a note to the Commission on Cements (1890), that traces of decomposition are visible in the lime

concrete works at Toulon; but, taking into account the general success which has attended the use of hydraulic lime in the Mediterranean, it is only fair to class such isolated instances of partial failure with that of the Portland cement concrete at Aberdeen, and not to allow them to discredit the employment of the material as a whole.

The quarries at Lafarge, which is the larger of the two works producing Teil lime, have a face half a mile in length, and over 300 feet in height. The limestone varies in colour from grey-blue to light yellow. It is easily worked, affording a good building stone for inside work, but too soft for face work. At Lafarge the stone is blasted down from the quarry face and broken into pieces small enough to pass a 3-inch ring. There are 53 kilns each (in the interior), in the form of two truncated cones, joined at their bases, and together about 40 feet high above the grating. They are what is known as running kilns, *i.e.*, fed continually with alternate layers of stone and coal-slack; while the lime is extracted periodically (generally at morning and evening) from under a grating at the bottom. Great care is necessary in feeding the kiln and extracting the lime to ensure that the layers sink evenly; otherwise some of the limestone is underburnt, whilst some is clinkered and spoilt. About 2½ cwts. of coal are used for each ton of lime obtained. The stone remains for three or four days in the kiln, the daily production of each kiln being from 17 to 18 tons.

The next operation is that of slaking, which is performed in a number of covered chambers fed in turn by each kiln, so that the products of the kilns are effectively mixed with each other, and any difference in composition corrected.

This process of slaking, which by English manufacturers is left to the users, or, in the case of ground limes, omitted altogether, is with Continental makers the subject of considerable thought and care. M. Le Chatelier, in a paper on slaking of limes and cements,* says that it is an operation as important and requiring as much care as the burning. It is, he says, essential to obtain complete hydration of the lime without altering the chemical condition of the silicates; and this can only be effected by the presence of water in a state of vapour. The lime should therefore be moistened throughout, but with no excess of water to any part, and then heaped together and covered up, leaving the heat evolved by the slaking process to turn the water into steam, which is absorbed as the lime falls to powder.

At Lafarge, the lime is tipped from the wagons (which bring it from

* "Extinction et silotage des chaux et ciments." M. H. Le Chatelier. (Bulletin Société d'Encouragement, 1895.)

the kilns) in a layer about 6 inches deep, and sprinkled with water by hand through a rose: the proportion of water used being 7 to 8 per cent. of the lime. It is then thrown up in a heap six feet high, covered up, and allowed to remain for from 8 to 15 days, according to the season of the year, by which time it is reduced to a fine powder. This is first roughly screened to eliminate any unburnt or overburnt particles of large size, and then passed through a sieve in the form of a revolving cylinder, with 1,500 or 2,000 holes to the square inch, which turns at from 60 to 80 revolutions per minute. The fine powder falls from this sieve directly into the bags. The residue is submitted to a second slaking process, and again passed through the sieves. What finally remains is ground up, and utilised for the production of a cement.

In other Continental works this second residue, which consists entirely of overburnt or argillaceous particles, is mixed with the lime, which it tends, if anything, to strengthen.

The importance of this fine screening is insisted upon by French writers, but rather, perhaps, from a theoretical than a practical point of view. It has, of course, been recognised for some years that extreme fineness is an essential quality of good Portland cement; particles which fail to pass a sieve of (say) 2,500 holes to the square inch being absolutely inert, and thus weakening the mortar in the direct proportion of the percentage present. With hydraulic limes, however, to which an addition of twice their volume of sand gives an actual increase of tensile strength, the case is somewhat different; and provided that the slaking process is carefully carried out, so that no unhydrated particles of lime are present in the finished material, it would seem to be doubtful economy to insist on the final screening in order to eliminate a small percentage of inert matter. Undoubtedly the ideal method with an English hydraulic lime (which is usually of a more variable composition, and with which the slaking process is less prolonged), would be to screen the hydrate through a sieve of 2,500 holes to the square inch, then to grind the residue to an equal fineness and mix it with the finished lime.

* Some interesting comparative tests were made by M. Candlot between the limes of Tiel, and of Tournay, in Belgium. The composition of Tournay lime is very much the same as that of Teil, as is shown by the analysis on page 44; but in the case of the Tournay lime the fine screening is omitted; and the residue on the various sieves is correspondingly greater.

* "Ciments et chaux hydrauliques." Candlot, 1898.

Comparative Tests of Teil and Tournay Hydraulic Limes.

1.—*Fineness.*	Teil.			Tournay.		
Meshes per square inch	2,100	5,800	32,000	2.100	5,800	32 ,000
Residue on Screens	2 %	8 %	19 %	9 %	14 %	33 %

2.—*Tensile Strength.*	Teil.							Tournay.						
	7 days	28 days	3 months	6 months	1 year	2 years	3 years	7 days	28 days	3 months	6 months	1 year	2 years	3 years
A. Kept in Fresh Water.														
Neat ...	43	98	160	226	234	238	321	43	85	177	265	313	306	2[illegible]
3 to 1 ...	60	117	230	257	308	332	292	45	101	202	321	412	335	3[illegible]
B. Kept in Salt Water.														
Neat ..	54	135	248	286	327	292	294	43	87	219	172	252	256	2[illegible]
3 to 1 ...	65	173	290	294	301	314	316	41	131	272	364	369	335	3[illegible]

The figures given above, which are those of sample, not of average tests, do not show any great difference between the two limes. That of Teil seems on the whole to increase gradually in strength throughout the series; whilst the Tournay briquettes, both neat and 3 to 1 mortar, show a tendency to diminish in strength after attaining a considerable power of resistance at periods of six months and one year.

A further series of tensile tests of Teil lime shown on page 49 is published by the manufacturers as the average of a large number of tests made in their laboratory. As is usual with makers' tests the strength of the neat briquettes comes out considerably higher than that of those made by an independent observer. The mortar tests are rather the other way, owing to the proportion of sand being greater: $3\frac{3}{8}$ to 1, instead of 3 to 1.

TENSION TESTS OF TEIL LIME.

(*Published by Manufacturers.*)

	7 days	1 month	3 m'nths	6 m'nths	1 year	2 years	3 years
A. Kept in Fresh Water							
Neat ...	57	120	246	312	376	384	450
$3\frac{3}{8}$ to 1 ...	48	90	163	174	195	213	222
B. Kept in Air							
Neat ...	65	105	163	215	336	566	545
$3\frac{3}{8}$ to 1 ...	54	100	170	196	267	341	455

The mean specific gravity of Teil lime is given as 3·8 ; the setting under water as commencing at about seven hours, and finishing at about 28 hours, after gauging.

In practice it is found that the setting of an ordinary neat briquette in air commences at about $2\frac{1}{2}$ hours, and is completed in about 23 hours. No rise of temperature is observable on gauging.

The author's experience with Teil lime was obtained on the construction of a concrete graving dock at Alexandria. This was built for the Khedivial Steamship Company, but for financial reasons has since been sold by them to the Egyptian Government, the steamship company in question having the use of an old but still serviceable floating dry dock, moored in the inner harbour.

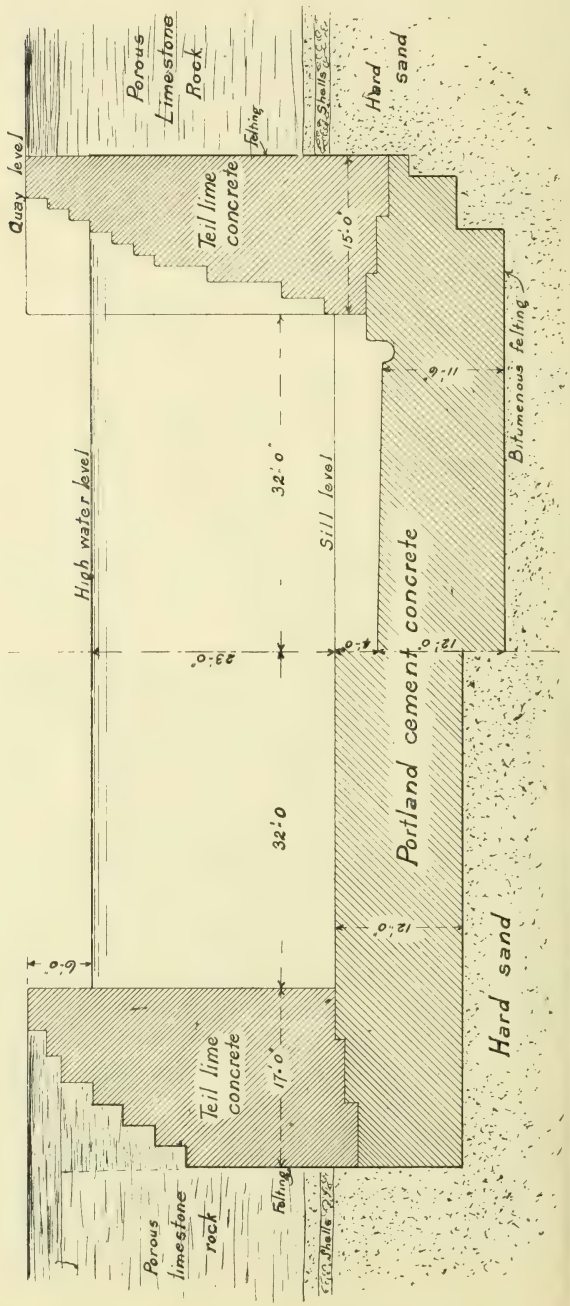
The new dock, the cross-section of which is shown in the figure (see page 50), has an effective length of 520 feet, an entrance width of 64 feet, and a depth of water over the sill of 23 feet at high water (about 21 feet at mean low water level). It is, although small compared with most modern graving docks, of sufficient size to accommodate any vessel ordinarily frequenting Alexandria, the draught of which is limited by the depth of water in a passage dredged through the outer reefs, and forming the only approach to the magnificent harbour.

There was no real engineering difficulty encountered during the construction of the dock, the site of which was entirely on dry land, on the low rocky shore of the outer harbour. The process of

— KHEDIVIAL GRAVING DOCK —

— Half Cross-Section —

through Entrance — through Dock —



excavation was, however, tedious and costly, owing to the large quantity of water which was met with, and which necessitated constant pumping; during several months as much as 600,000 gallons per hour having to be lifted about 45 feet.

The uppermost stratum consisted of a soft oolitic limestone of a very recent character. This extended to about 28 feet below the surface and was underlaid by hard sand, sufficiently compact to stand in a vertical face, though not so much so as to be classed as rock. Between the two strata were some curious layers of shells, cemented together into a hard mass, but individually almost perfect, and strongly resembling some existing varieties.

To a depth of 16 feet from the surface all spoil from the excavation was removed in baskets, carried on the heads of Arab labourers. Below this it was drawn out by ponies in Decauville skip-wagons, up two inclined roads, until a depth of 32 feet was reached, when two 3-ton cranes were installed on the surface, and lifted up the skips, which were detachable from their bogie-frames. The rock immediately seaward of the entrance was left as a natural dam until the dock was completed, and the caisson in place.

From the amount of water encountered in trial borings on the site, it was evident that pressure due to a full head of water must be allowed for on the floor and walls of the dock; and they were designed on this calculation. It was at first intended to construct both floor and walls of Teil lime concrete; but, from a series of tests made (on the site) while excavation was in progress, it became clear that a great risk would be run by laying lime concrete in a position where, as here, it would be liable to be flooded with water within a few hours of gauging. Portland cement was, therefore, substituted for Teil lime in the floor of the dock: proportions of 1 part of cement, 2 of sand and 6 of broken stone being specified; while for the Teil lime concrete in the walls the proportions were as 1, 2 and 5.

It was also decided to put a complete lining of Callender's bituminous felt between the rock or sand and the concrete of the floor and walls.

The sand bottom of the excavation was rendered dry and firm by a series of 12-inch and 9-inch pipe drains, sunk below formation level, and running into a central box shute (2 feet 6 inches by 1 foot 10 inches), which led the water to the pumps. The felt was laid in overlapping strips on the ground, and joined into one continuous coating by passing a hot iron between and over the edges; only as much being spread as could be covered with concrete within an hour or two. If by any

accident one of the pumps was stopped for more than a few minutes, the water rose rapidly to the previously dry surface of the ground, and forced up the felt (which had been joined into one sheet and weighted down at intervals) in a series of waves. This not infrequently happened at night, owing to the shortage of the municipal water supply (on which the engines were dependent) between certain hours. Concreting was carried on night and day, and it is probable that, in spite of close supervision, many of the joints in the felting opened by the upward pressure from this cause were covered with concrete before being detected, and thus prevented the felting from affording an impervious skin.

The concrete, both cement and lime, was passed from upper stages through gravity mixers on to a plank platform beneath the shutes, from this being shovelled into barrows to be distributed over the adjacent work.

Portland cement and hydraulic lime being thus used under practically similiar conditions and in nearly the same proportions, it was easy to compare them as regards ease of manipulation, and, to some extent, as regards the results obtained.

In the first respect the hydraulic lime concrete was much to be preferred. Continual difficulty was experienced in the floor of the dock owing to the quick setting of Portland cement in such a climate as that of Eygpt. All cement used was shot and stored in binns for at least a fortnight before being used ; and in some instances was turned over one or more times. In spite of this precaution, each thin layer of concrete was apt to set completely before the next could be added, and sometimes partially before it could be shovelled and rammed into place. When thicker layers, of three to four feet in depth, were tried, the frequent semi-vertical joints of their edges presented even greater possibilities of leakage under pressure.

No such inconveniences were experienced with the slower setting lime concrete in the walls. It was easily rammed into that plastic condition which betokens freedom from porosity, and presented a surface, even on the next day, soft enough to unite readily with the layer above, while sufficiently set to relieve the shutters of practically all weight.

The advantage of this quality was shown later, when the dock was subjected to the pressure of a head of water. No sign of leakage was visible then or later in the walls, whereas at first the Portland cement floor leaked slightly in a considerable number of places.

To remedy this defect a number of vertical holes were drilled in the concrete—9 feet deep and 15 feet apart—and Portland cement grout was forced into them under a pressure of 30 to 40 pounds per square inch, the water then being allowed to rise in the dock until the cement should be set. The porous places in the concrete were by this means rendered solid, and all tendency to leak stopped for the time.

On the other hand, lime concrete would have been, by reason of this slow setting, quite unsuitable for at any rate the base of the floor, which could not be kept free from water during construction.

The author has some doubt, also, as to how far the treads and angles of the altars will stand the severe usage to which they must be at some time subjected. Facework of special 3 to 1 concrete, 4 inches thick, was adopted on the surface of the walls; but only the same soft limestone (which could be cut easily with a heavy adze) was used; and this, with a matrix of lime and somewhat inferior sand, cannot be expected to prove entirely durable. It is to be regretted that some harder stone than that obtained from the excavation could not have been imported for the altars, whether in the form of ashlar coping or of a concrete facework.

The following figures are given as representative of a series of tests made on the works, partly to compare the three available sands. For permission to publish them the author is indebted to Mr. W. J. Binnie, M. Inst. C.E., Resident Engineer on the works for Sir Benjamin Baker and Mr. Hurtzig, the Consulting Engineers (the author acting as Engineer for the Contractors, Messrs. C. H. Walker and Company).

None of the local sands were of a really satisfactory character, so that the results obtained in these tests cannot be taken as absolute indications of the strength of Teil lime, though interesting in relation to each other. A sharp and fairly coarse sand is almost more essential for hydraulic lime than for Portland cement; and the Teil manufacturers state that one containing shells is particularly to be avoided.

The "crushed limestone" sand of the tests was obtained by screening the debris from the (hand-broken) stone used in the concrete. It contained about 50 per cent. limestone, the remainder fine quartz and small shells. It was sufficiently fine for one third to pass through a sieve of 2,500 meshes to the square inch.

The "quartz" sand was obtained from the neighbourhood of

Aboukir Bay. It was clean but wind-blown and far from sharp, and so fine that 80 per cent. passed a 2,500 sieve.

The third sand, which was excavated from below the limestone of the dock cutting, was coarser, but contained nearly 50 per cent. of broken shells.

The compression tests were made with $2\frac{1}{4}$-inch cubes, the stone for the purpose being broken to pass a $\frac{1}{2}$-inch ring. Cubes of the stone itself broke under an average pressure of $73\frac{1}{2}$ tons to the square foot. Portland cement concrete cubes made in the same proportions broke at from 50 to 60 tons at the end of five months.

Tension Tests made with Teil Lime at Alexandria.

I.—Neat Briquettes.

	7 days	28 days	3 months	6 months	1 year
Kept in Fresh Water ..	44	90	194	270	297
Kept in Salt Water ...	38	112	271	313	296
Kept in Air	40	100	125	169	240

II.—2 to 1 Mortar Briquettes.

All kept in Salt Water.

	28 days	3 months	6 months	1 year	$3\frac{1}{2}$ years
Gauged with Fresh Water.					
A. Crushed Limestone Sand	55	122	209	142	195
B. Fine Quartz Sand ...	38	111	122	130	210
C. Quartz with Shells ...	52	66	143	—	—
Gauged with Salt Water.					
A. Crushed Limestone Sand	63	162	175	166	—
B. Fine Quartz Sand ...	38	95	126	160	—
C. Quartz with Shells ...	90	128	166	—	—

Breaking weights in pounds per square inch.

COMPRESSION TESTS MADE WITH TEIL LIME CONCRETE AT ALEXANDRIA.

1 Lime, 2 Crushed Limestone Sand, 4 Broken Stone.

	28 days	3 months	5 months
Gauged with Fresh Water	11	24	30
Gauged with Salt Water	13	24	37

Breaking weights in tons per square foot.

Some of the concrete cubes, when immersed (in salt water) immediately after taking out of the moulds (48 hours after gauging), cracked, crumbled, and eventually fell to pieces.

No traces of decomposition were ever visible in those kept seven days in air before immersion.

It is interesting to note what consistently greater strength is obtained by gauging with salt water, especially in tension.

To complete these notes on hydraulic limes, it is necessary to make some reference to the excellent results that may be arrived at with a mortar composed of lime and burnt clay, or crushed brick. Even if a pure or "fat" lime be used, the resultant mixture is moderately hydraulic in character; while a tensile strength equal to that of Portland cement mortar may be obtained with a mixture of hydraulic lime, crushed brick and sand.

Both the Romans and ancient Egyptians employed mortar of this composition, with results that may still be seen to be admirable.

* In Mr. FitzMaurice's paper on the Assuan Dam, he states that it was originally intended to use lime and burnt clay as a mortar for the masonry hearting of this work; but that, to economise time, Portland cement was substituted after 13,000 cubic yards had been built. The proportions used were 2 parts of "fat" lime and 3 of burnt clay, with the addition of 10 per cent. of granite sand. The mortar was found to be more watertight than that of Portland cement (as one would have expected from the weak proportions of the latter :—4 to 1), and showed average tensile strengths of 160 pounds per square inch at 28 days, 321 pounds at six months, and 337 pounds at one year. It was not, however, cheaper than 4 to 1 Portland cement mortar, owing to the fact that all fuel used for burning both lime and clay had to be brought from England, whereas good sand was available locally.

* Minutes Proc. Inst. C.E., Vol. CLII.

The author has used a somewhat similar mortar in India, where, away from the coast, the employment of Portland cement is rare.

The lime in general use in the North-West of India is burnt from kunkur, a soft nodular or concretionary limestone deposited in past ages by the waters of the Ganges, and found in layers near the surface of the ground. It contains sufficient silicate of alumina to yield a lime of moderately hydraulic properties, and makes a fair mortar when mixed with river sand. Sharp sand is, however, often difficult to get, and a very much stronger mortar is obtained by the use of crushed brick, known as "surkhi," or by proportions of 1 part of surkhi, 1 of sand and 1 of lime. The usual practice is to separate the local bricks into three classes—1st class, for general engineering works; 2nd class, for inferior building; and 3rd class, which is crushed for surkhi, either by hand or in a mortar-mill. The author found a "Devil" disintegrator most economical for the purpose.

As an example of the use of such a mortar, the new East Indian Railway Bridge over the Sone, a tributary of the Ganges, may be instanced. The piers of this bridge, which is nearly two miles in length, are founded on pairs of masonry "wells," sunk on steel cutting edges 40 feet below the bed of the river, by grabbing the sand out from the centre, and building on successive rings of masonry. When in place the wells were filled with concrete, and the masonry corbelled out to the full dimensions of the pier.

The greater part of the foundation work was done during the hot weather, when the river bed was for the most part a waste of dry sand. At the break of the Monsoon this was quickly covered to a depth of 10 feet—the rate of the current being extremely swift for the first few weeks of flood.

A good test was thus afforded of the hydraulic properties of the mortar, the strength of which, even when only laid two or three weeks, enabled the masonry of the half-finished piers to withstand the force of the current with insignificant damage.

In conclusion, it seems to the author that properly selected and treated hydraulic lime might with perfect safety be substituted for Portland cement as a component of concrete in a large number of cases. Retaining walls, bridge abutments, and many similar works in this country are commonly built under conditions which would admit of its use:—viz., that water be excluded from the work during construction, and that no severe load be imposed upon it for a month or more after construction is complete.

The chief argument for the use of hydraulic lime, which has not

hitherto been touched upon in this paper, is that of economy. It is difficult to compare the cost of works in England executed with lime and cement, as the lime has usually to undergo various subsequent processes at the hands of the users, into which (for large works) the question of time may enter as an important factor.

Taking, however, the price at Marseilles of Teil lime and of French Portland cement (both ready for immediate use) a marked difference is at once apparent.

Teil lime (in bags) is now sold at 33 francs (say 26s.) a ton ; Portland cement at 38 francs (say 30s.) a ton ; the former averaging 65 pounds to the cubic foot, the latter 90 pounds. Hence we have a cubic foot of lime costing 9d. as against 1s. 2½d. for a cubic foot of cement ; and the difference in price between a cubic yard of lime concrete gauged 6 to 1, and one of Portland cement concrete gauged 8 to 1 would be nearly 9d. in favour of the former. With the cost of freight added the difference would be greater.

The Governments of Belgium, Switzerland and Germany have drawn up standard specifications for the manufacture and use of hydraulic lime, in accordance with results arrived at in their laboratories.

We in England are not so accustomed to rely on the aid of a paternal Government ; but it would seem that some such body as the Institution of Civil Engineers might, with advantage, institute an inquiry into the sources of English hydraulic limes, with a view to stimulating their scientific production, and suggesting some safeguards for their more general use.

DISCUSSION.

Mr. Fowler

Mr. A. F. Fowler said—Personally, I feel very much indebted to the author for this excellent paper because I think it has brought before us a subject matter which is not so familiar as it might with great advantage have been to all engineers engaged in harbour works.

I think, in the third paragraph, an explanation of that has been given, and a very good explanation, namely, that the properties of Portland cement are well known ; that there is a standard specification for its use, and all the engineer has to do is to specify a good make.

Then, again, we have the fact that nowhere in this country—unless we get to remote country districts, such as the mountainous districts of Wales or Yorkshire—are we in such places but that Portland cement can be brought to us very cheaply as regards carriage ; and therefore in estimating for public works it is the exception rather than the rule to specify anything in the way of hydraulic lime preferably to cement.

In works with which I have been more particularly connected, Portland cement concrete has been used almost universally because of its properties of setting readily under water. It has its disadvantages, one of which is want of plasticity whilst setting and of elasticity after setting, and following on these peculiarities its tendency to contract and cause frequently trouble when put down *in situ* in large masses. I think that, as regards harbour work, the use of Portland cement concrete will continue notwithstanding its disadvantages, but when we get abroad (say) into Egypt, where I have recently had occasion to form estimates for public works, one finds that not only is Portland cement objected to, but its cost is excessive, and a place has to be found where suitable stone can be procured for the purpose of making hydraulic lime. I thought at that time how ignorant I was as to hydraulic lime and felt I ought to have gone earlier into the qualities of such eminently useful material.

The author says, the term "hydraulic lime" is in itself somewhat vague, but I think after the very lucid explanation he has given as to what hydraulic lime is, we will be able to differentiate for ourselves as to its various component parts.

It appears to me that the principal advantage of hydraulic lime over Portland cement concrete is for the purposes of mortar. It has a

higher tensile strain and, as aforesaid, is more plastic, and where not interfered with by water, it is preferable as not being so brittle. Mr. Fowler

I feel at a great disadvantage in discussing the paper, inasmuch as I have not had the opportunity of using hydraulic lime; therefore, I think the paper is the more valuable as having drawn attention to the advantages of such material in positions where Portland cement concrete cannot be employed profitably by reason of its cost or other causes.

Mr. M. G. Ross said—I should like to endorse the author's remarks as to the value of hydraulic lime in this country. I have experienced great difficulty lately with reference to lime for Kirkdale new tunnel, where for many reasons I did not wish to employ Portland cement. To commence with we employed some so-called hydraulic lime which did not turn out at all satisfactory, it did not set sufficiently quickly. What we really wanted was not a Portland cement but something which would set reasonably quickly so that we could free the timber centres and proceed with the work. Ultimately, we had to take out two or three lengths of brickwork to tunnel of 21 feet each and then we got some Kirton-in-Lindsay hydraulic lime which turned out very satisfactory in the end, and we employed it throughout the work in the tunnel, but the specification we were working under would have been equally satisfied by the use of either of the two limes referred to. This leads me to endorse what the author says in his last paragraph: that "the Institution of Civil Engineers might, with "advantage, institute an inquiry into the sources of English hydraulic "limes, with a view to stimulating their scientific production." Mr. Ross

Of course, in such works as I have referred to, one does want a thoroughly hydraulic lime which will set under very damp conditions and under conditions where it does not get a free flow of air.

Mr. J. H. Parkin said—I do not see any remark in the paper as to the effect of frost on hydraulic lime. It is a rather important point. On the Kendal Fisher Tarn Works, although the concrete was protected, we had some trouble in this respect, and found it necessary to remove as much as six inches of concrete to which the frost had penetrated. Mr. Parkin

I notice in the different tables given in the paper there are some very curious results. From the tension tests on page 43 it would appear that a good deal depends upon the consistency of the mortar at the time of moulding into briquettes. I see the first lot made from the slurry direct from the mills does not come within 50 per cent. of those made from mortar of suitable consistency.

Mr. Parkin Some time ago I made some briquettes from ordinary ground lime, and found that, making briquettes immediately after gauging and letting the mortar stand over a day before moulding, the second lot gave results, up to six months, at 100 per cent. greater than the first lot, but going up to nine months the percentage got less. I quite endorse all that has been said about the suitability of hydraulic lime for works where there is not much water to be dealt with during construction, and where the hydraulic lime concrete can be given sufficient time to set before any considerable stress is brought upon it.

Mr. Cooper Mr. F. E. Cooper said—The paper has been a very interesting one, and the point that has struck me is the question of cost. In dealing with works such as the graving dock shown on the diagram, and with such names as are attached to it, one does not criticise, one only asks for information. I should like to know why, when such an expense was gone to of providing bitumen sheeting underneath the concrete, the proportion of 1 part cement to 2 of sand and 6 of broken stone was used in the construction of the floor. Of course, comparing a thick mass of concrete with the ordinary foundations one lays in the streets, we never think of putting it in stronger than 11 to 1, and any one who sees these foundations will be satisfied that it is a good job. Of course, the very fact of making the concrete of that strength conduces to its quicker setting, which is a difficulty which the author mentions. At the same time it will be more brittle and will lose the quality of elasticity which is claimed for the hydraulic lime.

On page 39, the author says, "Silica is apparently the most valuable "constituent if in a state to enter into combination. When in a "crystalline form, as grains of quartz, it is insoluble and consequently "inert." I should like to ask whether that is absolutely the case or not. Chemists hold that the sand which is used in ordinary lime mortar is not merely an addition to resist pressure. A proportion of that sand does actually enter into combination with the lime.

My own experience with regard to hydraulic lime is very small indeed. I have used it—with the same result that Mr. Parkin has mentioned—on one of our sewage farms and found that the joints fell right away, probably from the effect of frost, and the jointing had eventually to be done with Portland cement which we have not found coming out.

Then, on page 42, the author refers to the use of puzzolana, and further on, on page 56, to the application of burnt brickdust to the limes. We had occasion to do that some years ago in connection

with a large sewer trench adjoining a heavy building and with really astonishing results. I think the proportions of broken brick and stone were about 14 to 1 of lime. When I had occasion, a year or two afterwards, to go into the trench I found it was of tremendous strength—almost like rock. Mr. Cooper

Our own experience of lime, as Mr. Fowler remarked, is for the purposes of mortar. We use a considerable quantity of moderately hydraulic lime—we cannot call it a "fat" lime—and we use one part of the lime to two of crushed clinker and we get splendid results.

Referring to the tests given, the City Engineer's department are accustomed, for comparative purposes, to break inch briquettes with $2\frac{1}{4}$-inch briquettes, and there is really, taking the average, no difference in the breaking strengths per square inch.

At one time I thought there might be a little in favour of the 1-inch briquette owing to its having a greater amount of skin which appears to set more quickly than the interior.

Would it not be likely that, in the case of hydraulic lime, you would get better results with the 1-inch briquette than the larger size, because you must be dependent on the presence of air to a certain extent for the absorption of CO_2 in the case of all except the most hydraulic limes.

On page 47 the author says: "It has, of course, been recognised "for some years that extreme fineness is an essential quality of "good Portland cement; particles which fail to pass a sieve of (say) "2,500 holes to the square inch being absolutely inert, and thus "weakening the mortar in the direct proportion of the percentage "present." If you extract all the fine particles you would naturally assume that you get the best results from the powder. But it has been ascertained that if you abstract the powder by means of a Flourometer machine, you get a worse result than if you tested the cement as a whole. I grant that if you mix the abstracted flour with sand you will get a better result than by mixing the whole of the cement with sand in the same proportion, but it seems that the flour of the cement will not set thoroughly without a proportion of grit, so that it looks as if the alleged inert matter has a use after all.

The tests given on page 54 are very interesting. The City Engineer got some very astonishing results when the river approaches were being made. We had 3-inch cubes tested, and we got a result averaging one ton per square inch. The blocks were one month old and ranged from 3-inch cubes to blocks 3 inches by 3 inches by 2 feet 6 inches high.

Mr. R. Brodie

Mr. Robert Brodie said—I quite agree with what the author says about the difficulty of using lime where you have water to contend with. I was engaged on dock work in South Wales, and in removing part of the old walls was struck by the excellent quality of the masonry which had been built with Aberthaw lime, the best available material at the time those walls were built and probably the best hydraulic lime in the country to-day. I made a number of experiments, but could not get satisfactory results where the mortar was in contact with water before it had time to set. It was held that we had not treated the mortar properly and the old walls were pointed to as proving the suitability of the materials, but when we came to remove the foundations, faulty mortar was found, showing that in the olden time they had the same difficulty where the situation was wet.

Slaking is a thing which requires great attention and is one of the dangers of using lime, as this is frequently done by unskilled labour and sufficient care is not always taken to see that the lime has been properly slaked and for a sufficiently long time before being used.

The author refers to the failure of the Portland cement concrete at Aberdeen; I believe that was fairly well proved to be unsuitable cement, and therefore I do not think it should be held as telling against Portland cement on the whole.

Mr. Cooper refers to the strength of the concrete in the dock at Alexandria. I have had some experience in dry dock construction, and might be allowed to point out that that concrete floor has a pressure of 35 feet of water behind it which makes it very different from the floor he refers to.

Mr. West

Mr. Henry H. West said—There is one point I would like to refer to—the remark on page 44 by Mr. Deacon where he uses the word "Elasticity," and I rather wondered in what sense the word was used. Elasticity, I take it, is the power of a substance that is deformed by stress, to return to its original form and dimensions. I suppose glass is one of the most elastic substances we have in common use, but its range of elasticity is very small; I wondered whether Mr. Deacon meant the quality or the range of elasticity.

With reference to the strength of the concrete in the dock bottom, when I saw the drawing, before I heard the paper, I thought the sand was possibly a shifting sand which could not be relied upon, but the author's explanation is that it was so solid that it would stand in a vertical cliff. Probably the heaviest ship that would be taken into that dock would run to an average load of 20 tons or thereabouts per foot run of the length of the ship, so that in some parts it might be

considerably more than this weight, and as that load would be concentrated on the middle line, it would call for as strong a concrete as you could apply. Mr. West

Mr. Coard S. Pain said—I should like to ask if the author happens to know what mortar or cement was used by the late Jesse Hartley in the construction of the Liverpool docks. In some of the old Roman work also the mortar used was extremely hard. Mr. Pain

The President, Mr. Frank E. Priest, said—Perhaps it is that the author has a larger share of that optimism which pertains to youth than has remained with me that leads him to say that a few simple tests remove all further anxiety with reference to Portland cement. I should not have taken such a great interest in the paper if they did. My experience is that, while twenty years ago much anxiety was not felt, one now feels a great deal, and the more one gets to know and the more the manufacture of Portland cement is improved, the more care is necessary in, and the more anxiety attaches to, its use. Mr. Priest

I have, within recent months, had two or three cases of cement coming from makers of high standing which has proved utterly worthless, and I believe the worthlessness of the cement was not due to any bad qualities possessed by it as it was sent away from the makers, but really to its unfitness to stand the climate and the ordinary methods of use. Its manufacture had been so perfect that it was sent out in condition for immediate use and was not fit for the rough life cement has to lead before it gets into the work.

On page 41 the author gives an analysis of Barnstone lime which is remarkably similar to Portland cement. As a matter of fact, with the exception of silica, every item in the analysis comes within the figures prescribed for Portland cement by the French Government, and in that exception in the Barnstone lime is only 0·4 below the minimum in the French specification.

The author has mentioned the use of bitumen sheeting in the dock work at Alexandria. I think the use of bitumen sheeting for obtaining waterproof work must appear as of great importance to every one who has to obtain deep chambers of perfect water-tightness. While, undoubtedly, it is an excellent material, I am led to believe that, in many cases, it fails to procure water-tightness, though the failure may not be known. In few cases where it is used is it possible to test for water-tightness until the whole work is completed, and if then it is found that leakage occurs it is imposible to obtain access to the bitumen without pulling down or taking up the whole of the work,

Mr. Priest because, as a rule, the bitumen is laid behind walls or under floors of considerable thickness.

Mr. Cooper referred to a matter which arises indirectly from the paper and concerns the lack of strength in the finest ground cement. On consideration this does not appear so extraordinary as at first sight. If from the cement the finest ground particles are taken, it is evident you will have there the cement produced from the softest clinker and will have left out that produced from the harder clinker which makes the strongest cement. This is the reason for fine grinding. The object should be to grind the whole of the cement into flour and so to ensure the grinding of the hard clinker. Coarsely ground cements may contain a large percentage of flour produced from the softer clinker and the remainder may be hard clinker so coarsely ground as to be valueless as cement. If this were ground to flour it would be the strongest part of the whole.

Mr. Ellis Mr. Somers H. Ellis, in reply said—I must thank you very much for the kind way in which you have received this paper.

The first question which calls for remark is one from Mr. Parkin respecting the effect of frost on hydraulic lime. Of course, in Egypt, there was no question of frost; and my only experience of hydraulic lime in England was that obtained on the Midland Railway where Barnstone lime was used for mortar. There, of course, if brickwork was laid in frosty weather the top course or two had to be removed. One would imagine that from its slower setting the lime would naturally be more affected than Portland cement by the frost, and that a sharp frost occurring the night after it was laid, or perhaps within three or four days, might have destructive effects.

Then, with regard to the consistency of the briquettes, I think one would expect to find that briquettes made from very moist lime would be much less strong—judging from the analogy of Portland cement briquettes. Anything more than 25 per cent. of water in gauging Portland cement renders it very much weaker, as regards tensile strength, than in briquettes gauged as dry as they can be made; the same thing, no doubt, holds good with lime.

The first of Mr. Cooper's remarks, with reference to the floor of the dock, he regarded 8 to 1 concrete as being unnecessarily strong. Well, we were only sorry that it was not made stronger than 8 to 1, not from the point of view of strength, although, of course, the floor has to stand an upward pressure due to a 35 feet head of water—that is an important question—but with reference to the practical difficulties of obtaining an absolutely water-tight concrete, to obtain

a water-tight concrete there must be a sufficient proportion of cement to fill the interstices of the sand and a sufficient proportion of mortar to fill the interstices of the stone. Mr. Ellis

The least proportions which will fulfil these conditions are 1 of cement, 2 of sand and 6 of stone—and then only if the concrete be perfectly mixed. A higher proportion of mortar is advisable if absolutely water-tight concrete is required.

The question of the weight of a ship resting on the centre of the floor was no doubt also considered in designing the floor; but I think that any such downward pressure is more than counterbalanced by the upward pressure due to the head of water.

As to the silica being inert, I cannot, of course, speak with any authority on the subject. So far as I have read, the opinion of chemists, particularly of French chemists, is agreed that crystalline silica is almost absolutely inert. Crushed brick, on the other hand, has a distinct chemical effect on lime, and imparts hydraulicity by its associations with it.

The question of fineness of Portland cement the President has answered much better than I could have done. I must, however, point out that the sieve referred to as separating entirely inert particles of cement was not a fine one, being one of only 2,500 meshes to the square inch.

The setting of hydraulic lime is not dependent, as Mr. Cooper suggested, on the presence of carbonic acid in the air, because hydraulic lime will generally set under water. One can make pats of lime and put them under water immediately after gauging, and quite one out of three will set perfectly hard, showing that the setting is not dependent on the presence of air. The results of the compression tests given in the paper are certainly low, but this is chiefly due to the inferior quality of the stone used in making the concrete test blocks.

* In one of the Volumes of "Proceedings of the Institution of Civil Engineers" there is given a list of the building stones of Great Britain with their crushing tests; and I believe that every one of the stones mentioned there has a higher compressive strength than the limestone used at Alexandria, which broke, as mentioned in the paper, under a pressure of about 73 tons per square foot. The tests, do, however, show a considerable *increase* of strength for lime mortar.

I quite agree with what Mr. Brodie said about the inferiority of lime mortar for work which is actually in contact with water. As is remarked in the paper—of those test cubes of lime concrete which

* Vol. CVII.

Mr. Ellis were immersed in water within 48 hours of gauging, a certain number (actually about a quarter) cracked and disintegrated—showing that concrete made under similar conditions would have been quite untrustworthy.

The failure of Portland cement concrete at Aberdeen is merely mentioned as a parallel case with the failure of test lime concrete at Toulon. Neither can be cited as condemning the material as a whole.

As regards the elasticity which Mr. Deacon spoke of, I should imagine he had in his mind such elasticity as would prevent cracking when changes of temperature produce contraction and expansion in large masses of concrete. Unless there is a certain amount of elasticity in the material it must crack, and hydraulic concrete lime is more free from that defect than is Portland cement concrete.

I am afraid I know very little about the mortar used in the construction of the Liverpool docks. I remember seeing some remarks on the subject in a discussion on a paper read before the Institution of Civil Engineers. I think it was a paper on "Portland Cement," and one of the speakers made a remark about the mortar used in the old Liverpool docks being extremely hard; and I think * that hydraulic lime was used.

The Romans, if they could get hydraulic lime, used it alone. If only fat lime was procurable they mixed it with crushed brick or puzzolana. They evidently knew a great deal about hydraulic lime. I do not think puzzolana is ever used by itself, and I am not sure that it will set properly by itself. It is used with equal proportions of "fat" lime as a rule and makes a very useful component of mortar.

I was glad to hear what the President said about bitumen sheeting. As he observed, its use is often not a success owing to there being so many joints. If the least upward pressure comes on the floor before the joints are covered they are almost certain to be forced open and the sheeting no longer affords a water-tight covering.

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* Vol. CVII.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

FOURTH MEETING—14TH DECEMBER, 1904.

FRANK E. PRIEST, M. Inst. C.E.,
PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. GEORGE HUGHES and EDWARD JOHN NEACHELL, as *Members;* and Mr. W. EWART WHITTINGTON, as an *Associate Member*.

HEAVY MOTOR VEHICLES.

BY T. MOLYNEUX.

IN writing this short paper it has been the author's purpose to confine himself principally to the subject of such heavy motor vehicles as come within the provisions of the Locomotive on Highways Act, 1896, and the Motor Car Act of 1903, the first mentioned of which was designed to facilitate a more practical and extensive application of self-propelled vehicles on roads than had existed theretofore.

Briefly, the Act of 1896 abolished the necessity of "the man with the red flag" in the case of motor vehicles which do not exceed three tons net unladen, and legalised the use of one trailer, not exceeding one ton in weight, with certain other restrictions, while the later one of 1903 raised the tare limit from three to four tons.

With regard to the very vexed question of tare limit, the author had charge of some experiments which were made early this year to arrive at some data in reference to the effect which heavy motor vehicles had on macadam roads, and the results showed that with a gross load of $7\frac{1}{2}$ cwts. per inch width of tyre of the wheels, no appreciable harm was done to the surface of the roads, and the City Engineer of Liverpool, under whom these experiments were carried out, in giving

evidence this year before the Departmental Committee of the Local Government Board, formed to collect evidence so as to draw up regulations for heavy motor vehicles under the 1903 Act, laid great stress on this point, and the desirability of doing away altogether with any tare limit, but regulating the gross load in accordance with the width of tyre, and providing a maximum gross moving weight of any one vehicle and its own load, and a gross load for any one axle. On these lines, the author believes, the new regulations will be formed.

It cannot be admitted that the employment of heavy motor vehicles in this country has advanced as rapidly as its advocates would wish, and considering the lapse of eight years since the date of the first Act, too few heavy motor vehicles are in use. It has become the fashion to blame legislation. The 1896 Act cannot be held solely responsible for the restricted use of heavy motor vehicles; what it effected (unwittingly, it may be conceded) was, that it eventually compelled makers to so design and build vehicles meriting further legislative consideration. Had the heavy motor builder had from the start somewhat unlimited scope for the strength, and, in the main, consequent increase of weight of parts, a vehicle would probably have been produced altogether disproportionate to its work and would simply have been an abortion on the original conception. As a proof of the contention it is only necessary to compare vehicles designed, built, and worked within the last two years with those which made their appearance in the first few months after the date of the first Act.

Liverpool was among the first and foremost to recognise the benefits which the 1896 Act would confer, but also that at the very outset very slow progress was being made, and as a result, the body known as the Liverpool Self-propelled Traffic Association was formed, and conducted three sets of trials, in 1898, 1899 and 1901. Those of 1898 were encouraging. Fourteen months later, in 1899, a distinct advance was apparent, and certain recommendations of the judges led to the introduction, in those of 1901, for trial purposes, of a class of vehicle exceeding the three-ton tare limit, and although this class of vehicle was distinctly a success, there was not an overwhelming case for it as against the three-ton limit vehicles. One of the three-ton tare vehicles carried five-ton loads regularly with remarkable success. Nevertheless, the judges, in their report, deemed it advisable to recommend certain amendments to the then existing regulations, and these or a modification of them have now been embodied in the later Act of 1903.

Mainly, as a result of the above trials, the heavy motor vehicle, for the purpose under consideration in this paper, has resolved itself into one in which the propelling mechanism is derived from a pair of horizontal compound engines, placed under the body of the vehicle, the transmission to the driving wheels, which are in the rear, after passing through spur reduction gear, being either chain or toothed gear direct drive. The engines receive steam from a vertical boiler in the front of the vehicle, some makers using the water-tube, others the fire-tube type, solid fuel, gas, coke, or coal being led through an opening in the top of the boiler, which is most convenient as well as helping to regulate draught. A steam pressure of about 200 pounds per square inch is usually carried. The Ackerman system of steering is almost universal, and some very ingenious and effective methods have been devised and adopted for absorbing shock between the engines, transmission gear and wheels.

Of the wheels taken in conjunction with the springing of the vehicle, present designs cannot be considered too satisfactory, and many people are at work trying to work out a successful solution of the wheel problem. Attempts are being made to make spring wheels of various kinds, but no data are yet available: the successful heavy motor driving wheel has yet to be made, but its early appearance is important to the thorough success of the motor wagon, perhaps it is not too much to state, to its very existence.

The author proposes to enquire briefly as to the reasons for the tardy advance of the use of the heavy motor vehicle. They can be safely stated at once, viz.:—the early failures of motor wagons due to unreliability; their much too high first cost; the fact that no motor wagon has yet been made to cope with from seven to ten-ton loads; and their excessive vibration and noisiness.

In the early days of the motor wagon, their repeated liability to breakdown gave them a bad name in many minds, and it will take a considerable time for makers to convince prospective users that such is not now the case to the same extent. It is not difficult for anyone with a knowledge of the market value of machinery to recognise that the selling price of a motor wagon is much in advance of the average similar piece of work. Makers should recognise that this is seriously retarding its general adoption. The investment is heavy to commence with, and the subsequent interest on capital charge is a serious item in working expenses. With regard to the capacity of the vehicle, it must be in one load, at least equal to that which is quite commonly seen in Liverpool: an average of eight

tons. There is not room in the loading berths and on our already congested streets for double the number of vehicles, necessitated by the motor vehicle only being able to handle half the horse-drawn load.

It may be well at this stage to state the so-called disadvantages with which the heavy motor vehicle has to contend, viz., the unsuitable and variable character of the surface of the roads, the variation between extremely light and extremely heavy loads within the limits of the build of the wagon, the unequal loading of the vehicle, and the high speed at which the vehicle is liable to be driven. It must be admitted at once that these conditions affect very considerably the very important matters of tractive effort, vibration and noise, and these bear a very direct relation to the fuel bill, up keep of the vehicle, and its popularity.

The modern railway locomotive is probably the most efficient type of steam tractor in use. No doubt the present perfection of design and construction of boiler and engines, evolved by long experience, contributes to this in a large degree. Comparing, however, the rail locomotive with the road motor, we find that the former is self-controlled in definite paths by means of the flanged wheel on the rail, while the latter is guided in its course from without. That this fundamental provision of the flanged wheel on the rail of the locomotive is a very great factor in tractive effort there is no doubt, but it has, however, placed a limitation on its general use, and the absence of the flange on the wheel of the road vehicle is essential to its application, but hence the necessity for some other device to guide it. The nearer such device in operation approaches in precision that of the flanged wheel, the greater will the efficiency of the road motor approach that of the locomotive, and further, the work of guiding the vehicle will be less in proportion as the surface of the road approaches in evenness that of the rail.

It is open to question, however, whether a smooth polished steel track similar in surface to the rail is the one best fitted for the present road motor. An even surface, where all possible slip, caused by perpendicular and unnecessary side movements, both entailing extra work in steering, and therefore contributing loss in efficiency, is reduced to a minimum, and which has sufficient adhesion for traction, is in the author's opinion the one best suited for existing heavy motor vehicles, and from experiments, asphalte, or "metallic leather" as it has been aptly termed, comes the nearest to these requirements, and from the motor point of view, the asphalte roadway is as near

perfection as possible. Wood paving, on account of its resiliency, is a very good second. Well laid stone sett paving is not very much better than the best macadam. Boulder paving is extremely trying, while a sandy road bed is as bad as could be wished by the enemies of motor traction. All our roads are not asphalte or even good macadam, and were we to mark time in future developments of the motor vehicle until they had reached a state of tolerable perfection in the roads, it is fairly safe to say that we should never get much further with either the one or the other, and it may here be added that the existing stone sett paving in our large towns is economical, durable, clean and sanitary, and it is early yet to arrive at the conclusion that the character of our roads needs to be radically altered to suit the peculiar conditions of motors. The railroad had to be made for the rail locomotive, but the roads exist, and motors, the author contends, must be made to suit the roads, at any rate for the present, until it has been demonstrated conclusively that complete success cannot be attained in the motor itself without further help from specially improved roads, and this cannot be shown until the motor has been ridded of those vicious faults which are so apparent, and which would still remain, no matter what the condition of the roads.

The problem, therefore, for the immediate present, is, what methods can be adopted to enable a motor vehicle to accommodate itself to the varying features of the existing roads.

The object is to nullify or absorb instantaneously, but as gently as possible, all perpendicular movements caused by irregularities in the roadway. This object, at present, is being attempted in different ways, as, springs between the main framing of the vehicle and its axle; spring wheels; resiliency in the structural material of the wheels; the pneumatic tyre, &c.

It is perfectly obvious that for the effect of the irregularity to be counteracted as soon as possible, the existing pneumatic tyre is supreme, but the cost is prohibitive at present for very heavy vehicles; solid rubber tyres are less costly, while spring wheels are as yet experimental.

So far, springs between the main framing of the vehicle and its axle are almost the universal expedient, but something additional and more responsive is required. This problem of absorbing shock and vibration in the present condition of our roads is all important for road self-propelled vehicles, and it is fairly obvious that the solution lies in the design of the wheels.

The ordinary steel tyred motor wheel, although very economical in itself, and showing up fairly well on asphalte, wood paved and good

macadam roads, is very harsh on granite sett paved roads, and more particularly so on boulders or "kidneys." It creates excessive noise and vibration, and the effect, at fair speeds, on the machinery and framework is very detrimental, and very soon renders expensive repairs necessary to these parts.

The main essentials of the heavy motor wheel are :—first, freedom from slip or skidding ; second, capability of absorbing road shocks at its place of contact with the ground, and third, it must in itself be silent. The first quality would show itself in a reduced fuel bill and less wear and tear on the wheel itself, the second would cause a decreased maintenance charge on the vehicle generally, and at the same time contribute to that third desirable quality, silence.

Upon the first examination, it might appear that the first qualification was the all important one, but it is safe to state that the last is the most so. A silent wheel will ensure very largely a silent vehicle, and this means economy ; but, apart from the economical view, its importance cannot be over estimated, and motor builders should recognise this.

In connection with this important part of the subject, the author thinks that he cannot do better than quote in full from a leading article which appeared in "The Engineer" of 4th November, 1904.

"The engineer who wishes to make his machines popular will make "them silent. It is to this end that designers should now work. The "modern sham lorry or motor van is reasonably efficient. It does not "break down, and, to judge by the numbers now in regular use, it "must be cheaper than horsepower. Let builders be content, then, "with the measure of success they have so far achieved, and cast "about for expedients which will reduce noise. Nothing much can "be done in this direction, however, without an exhaustive study of "the whole subject. Unfortunately, the cause of noise is too often "obscure. Abundant examples of this are familiar even in ordinary "household life. Something will, of course, depend on the condition "in which the mechanism is kept ; but it is easy to see that what is "bad to begin with will become worse to a far greater extent than that "which began well. The absolute well-known certainty that much of "the noise now made is unnecessary will only strengthen the hands of "those who would prohibit steam haulage altogether in residential "portions of large towns. There is ample room for improvement ; "but no improvement will be effected until builders have had it forced "into them that noise can be diminished, and that to work successfully "in this direction will be found to pay. Silence is now of more

"importance in steam motor vans for town work than economy of fuel, "or, indeed, any other quality that we should name. Lacking silence, "unpopularity will set in, and legislative restrictions will again become "the rule. Then we shall hear denunciations of a narrow-minded "public opposed to all progress. Progress has nothing to do with the "matter. Steam motor vans are used instead of horses because they "do their work for less money; but the peaceable inhabitants of large "districts are not concerned with this, and they have a right to insist "that noise and vibration shall not disturb their lives. Fortunately "the two conditions are not incompatible; but it rests with the "builders and users of steam vans and lorries to reconcile them, and "see that they give no just cause of offence."

The author has abstained from giving detailed descriptions and characteristics of different types of heavy motor vehicles, and has also refrained from going into the many advantages of the heavy motor vehicle, sanitary and others, or of peering into the future as to whether the future heavy motor vehicle will have two, four, or more driving wheels, or whether the motor proper will be detachable from the carrying portion and other alluring possibilities, but has endeavoured to draw attention to the very pressing existing problems, more particularly the behaviour of the wheel on the road, as upon its early solution, the future of the heavy motor vehicle in any form is entirely dependent.

DISCUSSION.

Mr. Wilson

Mr. H. W. Wilson said—The author has made several references to the question of spring wheels for heavy motor vehicles, and as I am acquainted with several gentlemen who are designing different types of spring wheels, I should like very much to know if the author can give me any information about any experiments which have been carried out on this class of wheel. The question upon which I am desirous to have information is whether all the wheels tried have had the tyres absolutely solid, or whether they have sometimes been split up into segments with springs inserted between them. I fancy I once saw drawings of a wheel of this type, but it seems to me that anything of the kind would inevitably give trouble.

I should also like to know whether the axle of the vehicle moves relatively to the centre of the wheel or whether it remains fixed.

I do not think I agree altogether with the extract quoted by the author from "The Engineer." It appear to me that the writer of the extract, who condemns the heavy motor on the ground of noise, must be somewhat of a faddist. Of course there is no doubt that heavy motors do cause a very great noise, but there are many other vehicles that are not exactly silent. I thought the threat: "Lacking silence, "unpopularity will set in, and legislative restrictions will again become "the rule," was rather an exaggeration.

To my mind the great question with heavy motor vehicles is to make them pay. I know a considerable number of people who are using motor wagons, and their experience seems to be that it is not as cheap as horse traction. It certainly seems to me that the great question is that of the cost per ton-mile, and until this is settled, the question of the unpopularity of noise is not of great importance.

Mr. Allen

Mr. Edward Allen said—I think the gentleman who has already spoken has dealt rather slightingly with the man who has ears to hear. I want to speak in sympathy with that man. I live on the main road to Garston. Throughout the day the tramcars make a great deal of noise and in the evenings I still have to listen to them. Well, about twelve o'clock the last tramcar passes, but directly after that we may have steam motor wagons making their journey between Liverpool and Garston, and occasionally there are some of the Corporation motor wagons journeying from Tramway Road. I assure

you it is a very practical question, and a great many people would make a great disturbance if the nuisance was increased by an increase in the use of the heavy motor vehicle. I therefore agree with the author of the paper, that we want a machine which will not, by its excessive noise, add to the strain and burden of life. Mr. Allen

We have a considerable amount of haulage to do in connection with our Company, and I hope I may hear some comparative figures of the cost of motor traction as against horse traction, but Mr. Wilson seems to have the opinion that, in respect to cost, the motor wagon is not yet able to compete with the horse-drawn vehicle.

Mr. W. D. Kirkpatrick said—Referring to the question of design rather than the noise occasioned by it, the author, on page 70, says: "The modern railway locomotive is probably the most efficient type of "steam tractor in use." I should like to ask if, during late years, it has ever been tried to have two sets of equal diameter wheels coupled together by means of a coupling rod similar to the type of locomotive largely used for light express service work. Mr. Kirkpatrick

Although I can see there are considerable mechanical difficulties in the suggestion, it would enable a larger area of contact to be maintained with the road, whilst the disadvantages of large diameter wheels with their attendant evils of high or narrow platforms would be avoided.

There was a paper read before the Society last session, in which the question of large diameter wheels was gone into, and the author said that the platforms were as high as it was possible to make them, owing to the height of existing warehouse levels, &c.

With reference to the question of roadways, I think that setts, when well laid and heavily tarred, form quite as good a pavement as asphalte.

In this connection it appears from the trials that have been made, that although ordinary setts are heavy on the working parts of the machinery, the steam consumption on them appears to be very small compared with the amount used when running on any other form of pavement.

In conclusion, I should like to ask the author if lignum vitæ has ever been used as a tyre, owing to this material giving such eminently satisfactory results when fitted to the stern tubes and *A* frames of steamships, where it is subjected to very considerable wear and tear.

Mr. E. A. Rosenheim said—There are a few remarks I should like to make in connection with the paper. Mr. Rosenheim

I would not like to say I agree with all that is contained in it,

Mr. Rosenheim but with the substance, from my own experience of running motor wagons, I thoroughly agree. At the same time I must take exception to the author's remark that "it is not difficult for anyone with a "knowledge of the market value of machinery to recognise that the "selling price of a motor wagon is much in advance of the average "similar piece of work." I cannot agree with that at all. A motor wagon cannot be compared with an ordinary piece of machinery, such as a stationary engine or a dynamo. It has to be specially designed in every single part, and only the very highest class of material, with special drop forging and every wearing part hardened and ground, can be used, *i.e.*, to give satisfaction to the buyer; and, owing to the stiffness of the buying public, can only be manufactured in comparatively small numbers. That is one of the reasons why the selling price of the motor wagon up to now has been comparatively high. Another is, that the public are, and have been to a certain extent, paying the manufacturer back some of the money which he spent in experimenting in the early days. There is every indication, however, that motor wagons will, in the near future, be purchasable at lower rates than formerly, but it will be a long time before the public will be able to buy them on the same rating (say) as ordinary machinery.

With regard to the author's remarks on carrying capacity, I am very glad to see that he says the motor wagon should, in his opinion, at least, have to carry an 8-ton load. With the new tare regulations it is an impossibility to carry an 8-ton load; we have a 4-ton tare with the proviso that the total maximum moving weight should not exceed on any one axle 8 tons. Let us consider what this axle load means. Take the vehicle at 4 tons; coke, oil, spare parts, water, &c., 2 tons; making in all $5\frac{1}{2}$ to 6 tons. Suppose we have a load, now, of 8 tons giving up a total moving weight of 14 tons, distributed as $\frac{2}{3}$rds on the back axle and $\frac{1}{3}$rd on the front, *i.e.*, on the back axle we have a total moving weight of $9\frac{1}{3}$rd tons, which directly breaks the law. Unfortunately with a vehicle taring four tons it is almost an impossibility to carry with safety more than a 6-ton load, as the machine cannot do it without excessive upkeep charges. So that unless the Local Government Board will amend their regulations, I am afraid that this desirable load, which is the only paying one, will not be possible. If the law were so modified as to enable us to carry this load, which would pay in one journey, it would not matter how long the vehicle was delayed loading, and also, if by this delay, it missed its return load, the tonnage carried on the one trip would amply repay the user.

Mr. Rosenheim

With reference to what the author says as to asphalte, wood paving, macadam and setts, there is no doubt whatever that with wood pavement the repair bill is reduced by 50 per cent. as compared with ordinary setts. Setts save fuel in winter, but tend, through their hammering action on the wheels, to increase the repair bill.

I do not quite agree with the author when he says that "the "railroad had to be made for the rail locomotive, but the roads exist, "*and motors must be made to suit the roads.*" There is certainly something in that, but provided that a large enough diameter wheel could be used with sufficient width of tyre, I think that a lot of this trouble, which is caused by this vibration, and a lot of the noise trouble, would be done away with; but at the same time this method of overcoming the difficulty is impossible, for the reason that, any increase in the diameter of the wheel and in the width of tyre means a corresponding increase in your weight and a consequent cutting down of your load or else exceeding the tare regulations. Manufacturers are hampered in their designs and users cannot make their vehicles run so successfully or so cheaply as they could if these regulations did not exist. One of the chief objects of motor users and Engineering Societies and manufacturers, should be to urge upon the Local Government Board to withdraw these restrictions upon heavy motor vehicles. Something has been done to modify these regulations lately, and the makers are now getting out new designs, so that it is not possible to say yet whether the modified regulations have had good results or not.

As regards the wheel question, I think the author has touched on the most important point when he says that the most important thing is to obtain some sort of spring wheel. Pneumatic tyres are altogether out of the question on account of expense, and no rubber tyre has as yet been made that will stand under motor wagon loads, so that some form of spring hub or resilient wheel will be the salvation of the motor vehicle. This type of wheel is now receiving the earnest attention of engineers and constructors, so that we may hope to hear of something practical in the near future. That elastic or resilient wheels will reduce the repairs and upkeep bill there is no doubt. The most successful wheel which I have come across up to the present has been a composite wheel, having a steel centre, steel spokes and a wooden felloe and weldless steel tyre, but I am sorry to say these wheels are not very quiet.

I am inclined to agree with a former speaker that the leading article quoted from "The Engineer" is written by a faddist. I do not think

Mr. Rosenheim

the quiet wheel is the most important thing, and in this must join issue with the author. No man is in business for his health, and what a user tries to do is to run his vehicle to show a profit, therefore, to my mind, the most essential points for motor wagon wheels, from a user's point of view, are those which are going to enable him to run his machine successfully and cheaply, viz., resiliency, freedom from slip and freedom from skidding. Silence just at present is not the important thing to attain, but, as in all new industries, with the higher development of the manufactured article, this will follow in its natural sequence.

Mr. Cooper

Mr. F. E. Cooper said—The author points out the need for a noiseless tyre or wheel, and I think he could give valuable information as to the work of the rubber tyre which we tried some time ago, and as to its effect in reduction of the item for repairs on the motor vehicles.

I was reminded of some remarks made by a late President of this Society, Mr. George Farren, in which he was dealing some years ago with the question of sett-paved roads, and at a time when wood was very much in evidence. He insisted upon it that there was no necessity for wood paving at all if owners of vehicles would only shod their tyres with rubber. He was looking a good way ahead, as at the time rubber tyres were quite a novelty, but if makers of motor vehicles followed the lines laid down by the author they would probably be able to design a wheel vehicle which would give a much better result as regards work, while the inconvenience to the public would be reduced to a minimum.

The author has conceded the point that it is not necessary to reconstruct all the roads for the purpose of motor vehicles. We certainly cannot afford to put down asphalte. We are trying to do away with cobble paving, but at the present rate of progress it is improbable that cobble paving can be entirely done away with under thirty years.

Mr. Thomson

Mr. G. Carruthers Thomson said—With reference to the last speaker's remarks on the use of rubber tyres, I remember about 16 years ago, in Glasgow, the road engines for hauling the boilers and marine engines from the different workshops to the large crane at the harbour. These road engines had wheels about 6 feet diameter, and they would be about 15 inches wide, and they were covered with tyres about 3 or 4 inches thick of indiarubber. These indiarubber wheels did not stand very well, and they did not get a good grip of the ground, so to help them there were shoes put on right across and

perhaps 3 inches space between each. That did not add very much to the noise of the wheel, but it added to the life of the rubber, but did not stand more than a month at a time in constant use. Mr. Thomson

It was then decided to try gutta-percha composition, about $4\frac{1}{2}$ to 5 inches thick, and this was found to be very much cheaper, and it took a very good grip, and lasted considerably longer than the indiarubber tyres; but I understand the use of gutta-percha composition has been discontinued, owing to the close proximity of the boiler fires to the wheel tyres softening them when standing still for any length of time.

The weights drawn by these steam wagons was anything up to 50 tons, and they very often put on two for the sake of getting quickly over the ground.

With the gutta-percha tyres they were able to haul double the weight they could do with the indiarubber tyres.

Mr. Thomas Duncanson said—I confess to having felt disappointed at the pessimistic remarks of the author as to heavy motor vehicles. He has had considerable opportunity for using and testing them, but he seems not to have obtained such extraordinary good results as to make him speak enthusiastically on the subject. Probably in his reply he will give us some particulars of the cost of motor traction, so that the members may judge of the commercial progress attained. Mr. Duncanson

One point which has not been referred to in the discussion is the proposal that the vehicle should be allowed to have a standard weight per inch width of tyre. This appears to be more reasonable than the methods that have been adopted in the previous Acts of Parliament.

Mr. H. Owens said—I should like to ask the author what has been done to silence the heavy motor vehicles that are being used in Liverpool. When they first came into use the noise was very excessive, but during the last nine months I have noticed that they run much more quietly. Mr. Owens

Mr. Molyneux, in reply, said—I am most gratified at the discussion which the paper has provoked. It is certainly a contentious paper; I meant it to be such. Mr. Molyneux

With regard to Mr. Wilson's, Mr. Allen's, and Mr.. Rosenheim's remarks as to the noise. Leaving out Mr. Allen's, the other two speakers were in one class. They belong to the class who use the wagons to make them pay, and they do not care very much about the noise, but the noise question is really a very real one, there is not

Mr. Molyneux the slightest doubt about that. There is a very large petition being signed now in London for presentation to the Local Government Board on the matter.

Mr. Wilson's remarks as to spring wheels. The spokes are supposed to be the springs. Several attempts have been made in this direction. There are four running on one of the Corporation wagons with very good results, and we have had several attempts to improve on them, but I think, perhaps, hardly in the right direction.

With regard to Mr. Kirkpatrick's remarks *re* loco. wheels and about the four coupled wheels. Well, they are complicated at present. Mr. Calthrop is at present engaged in the design of a four coupled motor wagon with a leading bogie, and he expects great results, but it has to be tried yet.

I should say lignum vitæ would be much too brittle.

As to greenheart, Mr. Rosenheim would be able to tell you a great deal about that. Curiously enough, timber on end does not do anything like so well as with the grain running circumferentially.

Mr. Rosenheim's remarks as to selling price of motor vehicles, I really do not see where the money is in the motor vehicle. I think it ought to be sold for £300. At any rate, a 4-ton tare weight of vehicle ought to sell for £75 per ton—much in advance of the loco. even assuming that they are not turned out in large quantities. "The manufacturers have to put down so much money in experimenting," I have no doubt this would be the reply.

With regard to Mr. Rosenheim's remarks as to width of tyre, you can overdo it, I think, in making the width of tyre too much, because you have the contour of the road to take into consideration.

If you get too wide a tyre you will not get as good a bearing surface; that was brought out in evidence before the Committee in London. You will see that, of course, in the case of the ordinary steam roller.

It is worth while to read up the evidence on the Local Government Board regulations. The opinions are somewhat remarkable.

The composite wheel has the fault of being metallic, and that is noisy without a doubt.

The Corporation has tried solid rubber tyres and the repair bill went down at once. It was most remarkable—50 per cent. easily—and while they were on, well, life was worth living—there were no complaints whatever, but the driving tyres only last 900 miles and the steering tyres only 1500. Of course the cost was prohibitive. The first cost of the tyres was, I think, about £70.

Mr. Thomson's remarks were very interesting. The use of gutta-

percha had never struck me. I should think it would give good results. Mr. Molyneux

The question of return loads for vehicles is important. It makes all the difference between profit and loss. That has been proved time and time again.

As to Mr. Duncanson's remarks about costs, perhaps the least said the better. They are not so bad, and I am not pessimistic about motor wagons at all. I think there is a great future before them, but somehow I do not think we are on the right lines. It is a much too complicated question to go into now, but I do not think we are on the right lines. Mr. Holt has mentioned more than once that the motor must be detached from the body of the wagon. I agree entirely with that view, and in fact Mr. Calthrop's design now is coming that way very much.

Mr. Owens' remarks about noise—I would not like to say what we have not tried to quieten the wagons. We have tried everything.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

FIFTH MEETING—11TH JANUARY, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. JAMES CONNER, ERNEST GRIFFITHS, W. M. HARRIS-BURLAND and C. H. MOGER, as *Members*.

SHIP AND ENGINE EQUIPMENT.

BY J. GRUNDY.

IN consequence of the large number of failures of shafts, &c., which have occurred during recent years, the author made enquiries into the circumstances attending them, and at the same time looked more closely into the question as to how the various parts are dealt with by the Authorities. In this paper is given some of the results of the author's investigations as affecting the more important parts of a vessel's equipment.

The rules of the Board of Trade, Lloyd's Register of Shipping, and the British Corporation Register of Shipping, are respectively "rules of thumb" or guess work.

Each Registration Society has two rules for shafts, and so, with the one of the Board of Trade, we have five rules in all for this vital portion of the ship's machinery, each of them differing from the other. This is a highly anomalous state of things, more especially when considered in conjunction with the fact that there can be but one rule for the strength of a shaft and therefore there is no room whatever for varying rules. This paper is not intended to, nor does it attempt to teach the Members of an Engineering Society how to work out the

strength of a shaft, if it did it would amount to an insult. As, however, it is necessary to endeavour to make the explanations clear enough to be understood by non-practical men, the author may mention that the only possible rule for torsion, *i.e.*, the strain under which a shaft works, embraces the power, the leverage at which it is applied, and the breaking strain of the material, without which it is impossible to make a calculation except a vague one by "rule of thumb." In addition, the factor of safety, or in other words, the number of times the shaft is made above the destructive or breaking strain, ought to appear in each case.

The rules of the Board of Trade and the British Corporation for Shafting are similar in some respects, but as it is unnecessary to go fully into them the author will at once point out as an illustration of their defectiveness that both rules are based on the square of the diameter of the high and low pressure cylinders. This cannot be right—the diameter of a cylinder is not squared in order to arrive at the strength of a piston rod, or a connecting rod, or of other parts, why therefore, apply that formula to determine the strength of a shaft? A bridge designer would not square the length of a railway train to ascertain the strength to make a bridge, he would on the contrary calculate it from the definite weight and stress the bridge had to carry or withstand, at the same time using the breaking or destructive strain of the material and a factor of safety. The total strain on a piston may be worked out in tons, and it is this strain applied at the leverage which turns the shaft, and which would break it if it did not possess the necessary strength. These two factors (power and leverage) are known and form the basis of the only rational and unimpeachable formula possible in order to ascertain the diameter of a shaft. Both these rules referred to use constants for crank angles. These may or may not be correct, but constants are to be avoided unless accompanied by a full explanation as to how they are derived. Under any circumstances they are not required for working out the size of a shaft. The rule of the British Corporation is the only one that takes into consideration the coefficient of displacement of a vessel at four-fifths the moulded depth, but this can have nothing to do with what is necessary to provide for the strength of a shaft; a proper factor of safety is all that is required.

The rules of Lloyd's Register of Shipping for Shafts do not take into consideration the question of displacement, nor do they have constants for crank angles. They are, however, made up of constants in other respects. The diameters of the cylinders are not squared, as

done in the Board of Trade and British Corporation rules just referred to, they have to be multiplied by decimals, the result being, it is presumed, something which represents the power exerted by each cylinder, or, to be correct, part of the power exerted, as, strange to say, the boiler pressure is taken into account later on in the rule. Now cylinders in each class of engine are proportioned to give out equal power; if, therefore, we take for example a triple expansion engine, and multiply the diameter of the cylinders by the constants provided respectively for them, the results are unequal, and to a considerable extent. This is strange working considering that the power may be obtained direct from the area of the pistons. Why therefore multiply by some absurd decimal constant down to as low as ·0013, different constants, which no one understands, being arranged for each class of engine.

The diameter of the propeller shaft depends to some extent on a result obtained by multiplying the diameter of the propeller by ·03 to which must be added another constant of ·63. Why such working as this? If there is anything in it, it is nothing more or less than a question of leverage. Further, it is laid down in these rules that the stroke, in order that it may fit the rules, must not be less than one half the diameter of or greater than the diameter of the low pressure cylinder. It would be just as sensible to say that the stroke must be proportioned from the funnel. It is a most extraordinary provision to make. A rational rule takes in any stroke and does not in any way require stipulations to make either the cylinders or stroke suit it. In these rules the author is still dealing with those of Lloyd's Register, the stroke is also multiplied by a decimal constant, each description of engine having a different constant. Taking a triple expansion engine having a stroke of (say) five feet, this in inches is to be multiplied by ·0165, resulting in the leverage at which the power is applied being taken at ·99, or practically one inch. This is unintelligent working. It need not be pointed out that the effective length of all levers should be taken when making calculations and not a fractional part of them. If you had to calculate the weight required at the end of a safety valve lever the full effective leverage would be taken and not a fractional part of it, and the same would be done in the case of other levers. Take, for instance, a winch handle 15 inches long—this would be a stroke of 30 inches which, according to Lloyd's rule, would have to be reduced to under one inch in order to arrive at the gearing required and the strength of same to lift a given weight. A winch maker would make his calculations from

the effective leverage and not from a part of it. Moreover, the stroke should be taken in feet—when making torsional tests the power is taken as applied in feet and not in inches. There is another point in these rules of Lloyd's Register which, by itself, irrespective of all other considerations, condemns them in this matter, and that point is the adding together of the power, or part of it, and leverage. This is most astounding and should be abolished. In the rules of the Board of Trade and the British Corporation, the power, so found, is multiplied by the leverage; in the case of Lloyd's Register they are, as just mentioned, added together. It is impossible for both ways to be correct, and it is Lloyd's rules which are wrong. This matter is again referred to later on. We now come to the formulæ for rudder heads. There is one point in the rule of the British Corporation I am pleased to give credit for—the calculation starts from the centre of pressure, and this is the only commencement possible in order to have a sensible calculation, but it is a pity this indisputable way of working is not carried through the remainder of the formula. The mysterious constant again appears, and in this instance it is ·26 for steamers and 1·26 for sailing vessels, although the rudder head of the latter is liable under certain circumstances to the same strain as that of the former. In the rule of Lloyd's Register the full breadth about of the rudder is incorrectly taken and the inevitable constant which appears is 1/32. An extraordinary feature of this rule is that the immersion of the rudder in feet has to be multiplied by the dimension taken for its breadth in inches. What is the result of multiplying feet by inches? It is not square feet or square inches; it is something which can possess no value whatever, and, therefore, condemns the formula. Again, in the former rule the immersed area is taken and in the latter the draft in feet, but a sea, being impartial, takes no notice of these and strikes the whole surface. In both rules the speed is squared, therefore a vessel steaming (say) 15 knots must have a larger rudder head than one making (say) 10 knots, although the strain is liable to be, and, in fact is, at times the same in both cases. When a rudder is hard over the strain increases with the speed, but this is unimportant compared with what the parts have to withstand when the rudder is struck by a heavy sea. It is this which must be considered, as it causes an enormous and, at the same time, a sudden strain. Again, Lloyd's Register stipulates that, if the size of the rudder head as found by the rule is less than given in the table, it is to be made to the latter. Why two methods? Surely one only is necessary.

As the term "constant" appears several times in this paper, it is as well to explain its bearing on the matters with which it is used. It is possible to invent any number of rules (five have been cited) all differing in formation, to obtain the diameter of a shaft, and also to arrive at the size or strength of other parts. These so-called rules do not give the result direct—something is introduced to make them work out to the required result, and it this factor which is known as a constant, and which may consist of a whole number, or it may be represented by a fraction. By the aid of constants any number of different formations of rules can be made to give the same result; they may be used to proportion one piece of machinery from another similar part, but they are unreliable and should be avoided, as by their use the breaking or destructive strain, or in other words, the quality of the material, may be, and, in fact is, ignored.

In the five rules, of which some particulars have been given, tests for torsion (under which shafts work) are not required, the breaking or destructive strain of the material being ignored, nor is there any mention of factors of safety. These so-called formulæ are therefore "rules of thumb," or guess work, and in regard to them we consequently do not know what we are doing. It is absurd to say that sensible calculations can be made by the use of constants and without taking into consideration the breaking or destructive strain of the material being used, and the power and leverage at which it is applied, both of which are known. Why have we such rules? The cry is for more diameter and not for sensible rules and good material. Call a shaft "wrought iron" and all sorts and conditions of scrap material may be put into it. Even if the diameter, the only dimension noticed in the rules, was arrived at in a rational manner, of what value are certificates so long as crank webs, their shrinkage and the keying of them on, together with couplings and coupling bolts, go unnoticed. All these parts belong to shafting and they are important. This is a serious defect as there have been many failures of shafts in consequence of the webs coming loose. It is not surprising that shafts have given trouble. Several shipowners might be mentioned whose steamers have run practically free, or as free as they can be expected to, from accidents. This is due principally to the use of the best material, and as this is possible in some companies it is possible in all. The author does not wish it to be understood that he believes accidents may be avoided altogether, but certainly believes it possible to do away with a large percentage of them.

Another point well worth calling attention to is that the rules

and regulations of Lloyd's Register permit of two sizes of propeller shafts, viz.,—one fitted with a continuous liner and the other having two short liners. The former is allowed at a smaller diameter than the latter. A continuous liner is expected to prevent corrosion of that part of the shaft which is inside the stern tube, and some hold the opinion that it gives additional strength, but, if so, it must disappear at the ends of the liner, where there can, of course, be no extra strength above that due to the bare shaft. Moreover, there may be corrosion at the after end. However, under any circumstances, corrosion has nothing to do with the matter so far as the rules go, as they call for minimum sizes, therefore a shaft fitted with a continuous liner must be weaker than one having two short ones. Again, it would, to say the least, be most unfortunate if a steamer, having a propeller shaft made to the rule which works out to the small size, arrived at a foreign port with a defective continuous liner, and there found it impossible to obtain a new one in one length. In such a case the shaft, being below the requirements for two short liners, would, it is presumed, be condemned, thereby involving serious detention of the vessel and heavy expense in consequence. It would be interesting to know how the authorities would act in a case such as this.

We now make reference to three matters of very great importance when considered in relation to safety of life and property at sea. The first of these relates to propellers. Although there have been so many accidents to these, viz.—145 in four years, exclusive of those lost in consequence of shaft breakages, such notice as has been taken of the matter by the Board of Trade or Register Societies is quite insufficient and the failures therefore continue. This is most extraordinary and there must be something to account for such a disgraceful state of affairs. The author would not like to say that it is due to indifference to the question of safety of life. It is one of the many matters which he finds it difficult to speak of in moderation. Propellers may be made of any quality material and to "rule of thumb" as to strength, hence they continue to break. Although shafts are of no use if the propeller goes, a very great deal has been made of the former and nothing of the latter, for the simple reason, no doubt, that it is easier to tackle a shaft than a propeller. The second matter relates to steering machinery, which is practically ignored by the Board of Trade and the Register Societies. There have been many failures or breakdowns of this, and apparently these may continue to cause trouble and danger to those who man the vessels. Ships have been lost by such failures, but even this does not seem to have any weight.

There is a comparatively recent case of a steamer being abandoned and lost in consequence of the cargo shifting, this being brought about by the vessel being thrown on her beam ends by reason of the breakdown and complete failure of both the steam and hand steering gears, the crew fortunately, after a terrible experience, being rescued by a passing vessel. It need not be mentioned that reliable steam and hand steering gears are of vital importance, and it is quite time the classification bodies dealt with them. At present many of them are wretchedly proportioned. As an example of this the weakest possible form for arms of cast steel quadrants is allowed under the rules, and in addition, the pins at both ends of the arms or connecting rods of many right and left hand screw gears are allowed to be made the same diameter, although in one case they are supported at both ends, and in the other they are overhung or supported at one end only. There is very considerable difference, too, (at least 4 to 1) in the strength respectively of these pins, although all of them have to withstand equal strains. The pins at the crosshead end of the arms—those which are supported at one end only and therefore at least only one fourth the strength of those at the other end of the arms—have failed many times in the work required of them. There should be proper rules provided for these vital parts. The matter is all the more important as there are now so many steam gears working the right and left hand screw as the main steering arrangement. The third point it is desirable to mention has reference to three sets of triple expansion engines the author has in mind at the moment which ought not to have been allowed to be put to work.

It should now be mentioned, however, that in the case of one set, the information is by report, but can be relied upon. In these the steam receivers of the intermediate pressure cylinders in all three engines were practically unstayed, therefore unsafe, and as a consequence two of them have burst. The author feels certain that the designer did not think them weak or likely to prove inefficient, or he would not have allowed the work to go on. It has only to be added that these three sets of engines were built under special survey and classed 100 A1. The rules not being sufficient to prevent the possibility of dangerous work being turned out, the inefficiency of these cylinders and receivers would in all probability have been detected had water tests been applied in the survey. These tests should be employed in every case, and it should be compulsory to do so, though it must not be taken or considered as a complete safeguard against faulty design; something more is necessary. In the classification rules the staying

of boilers, for example, is provided for, but, strange to say, no provision is made for the staying of steam receivers of cylinders, &c. Plans of boilers have to be submitted and certified to by classification bodies, and there is therefore no reason whatever why plans of cylinders with their receivers and also plans of all other important parts should not be similarly dealt with.

The author is informed that the engines to which he has alluded were for "spec" built vessels, consequently there was no owner's superintendent to exercise suitable vigilance in regard to them. Other instances might be given, but those to which attention has been called suffice to emphasise the fact that vital matters are overlooked in the rules and regulations. It is strange, for instance, to make so much of shafts and to ignore propellers, to have regard to plans of boilers and not to those of cylinders, and to provide so elaborately with respect to cables, and to take such little notice of steering gears which are far more important. The breakdowns to steering gears which we hear of—there are many not reported—practically in all cases occur during heavy weather, and not during ordinary steaming. A heavy sea striking the rudder causes an enormous and sudden strain, and this coming on the other parts, some of which are too weak, yield to the blow, and disablement consequently follows. This does not receive the consideration it calls for, for it is undoubtedly the case that a large majority of the failures are due to haphazard design and guesswork. It is quite time these matters were taken in hand by the classification bodies so that through their rules the various parts shall be made strong enough for the work they have to do. Lloyd's Register have a rule for steering chains which has a constant of ·38. The corresponding rule of the British Corporation has a constant of ·145. Both these rules are unreliable, as they do not take the power and breaking strain of the material into consideration.

At this point it might be mentioned that although the Registration Societies take notice of two or three parts only of steering gears, many other of their parts which are, at least, equally important, go unnoticed.

It is nothing but right to say that the wretched "rule of thumb" or guesswork system is, fortunately, not yet quite universal, but it is gradually eating its way deeper and deeper into Shipbuilding and Engineering practice. This is not surprising seeing that the system is followed by those bodies who are supposed to lead us. The matter has another aspect which ought to be mentioned. We owe at least some consideration to students and others who follow us, and who

naturally accept, without question, the rules of those in authority. A student would, however, know better than add power and leverage together as is erroneously done in the rules of Lloyd's Register for shafts. It can be imagined the disastrous results if he did not know better and act upon this knowledge. Take, for example, a cylinder having a total strain on the piston of (say) 30 tons and with a stroke of four feet. According to Lloyd's this would mean 34, and if with five feet stroke it would be 35. What would happen to the shaft in the latter case? In accordance with the rules of the Board of Trade and the British Corporation, which are correct in this respect, the former would be 120 and the latter 150. There is here, of course, a considerable difference. It need not be added that this is a serious matter; for mistakes might be made in dealing with other leverages and powers in the same way. The fact of this formula being modified or corrected by the introduction of a constant only makes the matter more confusing and mysterious.

It will be noticed that mention has been made of the Board of Trade, Lloyd's Register Society of Shipping and the British Corporation for the Register of Shipping. Other Societies might be added, but in this paper we are confining ourselves to those which are exclusively English. We trust, however, it will not be out of place if we state here that in the rules of the Germanischer Lloyd due provision is made for the strain per square inch of piston rods, connecting rods, crossheads, pump levers, main bearing, holding down, and coupling bolts. Although we do not agree with the strains allowed for these important parts we think it well to make the reference, as in this matter the German rules are in advance of anything done by the British classifying bodies mentioned above. So far as the main machinery is considered, there is more Engineering on one page of the Rules and Regulations of the Germanischer Lloyd than is to be found in the workings of the Board of Trade and English Registration Societies put together.

It is necessary to bear in mind the fact, one which the author is afraid is gradually being lost sight of, that before machinery (main and auxiliary) can be made, it must be properly designed and its various parts calculated or worked out in such a manner as will insure it being of ample strength to perform the work required with the maximum of safety. It is at this, the designing stage of both ships and machinery, for which certificates will be sought that requires to be crucially dealt with by the classifying authorities. There is urgent necessity for practical rules and regulations to be adopted.

The author desires to point out that he does not, in any way, reflect on the outside staff of the Board of Trade and Registration Societies. Having many years' experience of the Surveying Staff of the Board of Trade and Lloyd's Register of Shipping, he can testify that their work, which is most valuable, is, so far as the defective rules and regulations call for it, well and thoroughly done, and in this respect they set an example which might with advantage be followed elsewhere. He does not wish to detract from the bodies mentioned but to add to their efficiency and importance. His plea is for them to abolish "rules of thumb" and guess work, and to adopt practical rules and regulations; rules which take into account the breaking strain of the material, give factors of safety, and do so without constants. When this is done, and not until then, there will be fewer accidents, and therefore greater security for life and property at sea.

The author has not by any means mentioned all the points which might with advantage be reviewed in connection with his subject, but he thinks this paper touches on a sufficient number without trespassing too much on your time, and to give opportunity for a fuller discussion than would otherwise be possible.

DISCUSSION.

Mr. Wilson

Mr. H. W. Wilson said—I am somewhat at a disadvantage in discussing this paper because I am not familiar with the rules which the author attacks. I sympathise with him when he complains that the various Registration Societies have different formulæ, but I rather take exception to some of the things which the author says in the paper. He uses the expressions "stress," "strain," "power," "load," and "leverage" in rather unusual ways. Now "stress" may be defined as the load per unit area and "strain" as the deformation produced by a "stress," but throughout the paper he uses the terms both "stress" and "strain" to indicate the load on the shaft or other part of the machine with which he is dealing, and I think it would simplify matters if a few alterations were made in this respect. Again, the author used the terms "power" in at least two senses, and I do not think either are quite correct. First, on page 83, he refers to those two factors, "power" and "leverage," where it seems to me he means "load" and "leverage," and again, on page 98, where, referring to chains, he speaks of Lloyd's Rules and says: "Lloyd's Register "have a rule for steering chains which has a constant of ·38. The "corresponding rule of the British Corporation has a constant of "·145. Both these rules are unreliable, as they do not take the "power and breaking strain of the material into consideration." I think the author must mean the "breaking strength" and not the "breaking strain."

Dealing now with his criticism of various rules, the author objects to the fact that in arriving at the strength of the shaft, some of the Societies use the square of the diameter of the high and low pressure cylinders, and points out that this cannot be right, as the diameter of a cylinder is not squared in order to arrive at the strength of a piston rod or connecting rod or any other part. Now, I do not follow the author at all, for I have always understood that in order to get the load on a piston it was necessary, in the first place, to square the diameter of the cylinder, and it seems to me that any rules based on the square of the diameter of the cylinder must have, at all events, a substratum of scientific accuracy.

From a careful reading of the paper it appears that the author's chief objection to the Board of Trade and Registry Rules is that they use constants and do not in all cases give the strength of the material and the factors of safety employed. Taking the case of shafting, two rules are in use which have been deduced directly from theory

Mr. Wilson

and experiments. In the one case the strength of the shaft is based on the experiment on the torsional strength of small test pieces, the basis usually being the strength of a 1-inch shaft when tested with a weight hung at a distance of one foot from the centre of the shaft, the strength of the shaft being said to vary as the cube of the diameter. This, I take it, from the reading of the paper, is the type of formulæ to which the author would have us work. The trouble in this case, however, is that while the strength of the material in the 1-inch shaft to resist torsion is accurately gauged by an experiment of a shaft of that size, it by no means follows that the value of the material in a 12-inch shaft is equal to that in the 1-inch shaft, as if 1-inch diameter test pieces be taken (say) from the near centre and near the outside surface of the 12-inch shaft, and such specimens be subjected to torsional stresses, the result would be found to vary very considerably.

Another formula used to determine the strength of shafts is one in which the moment of torsion is equated to the product of the moment of the resistance of the section and the greatest shearing stress, or $T = f Z$.

In this case, however, great care has to be taken in using the formula, as otherwise very incorrect results can be obtained. As a matter of fact this formula simply gives the greatest shearing stress on the material when stressed within the limit of elasticity. If used beyond that limit the results are altogether erroneous, and, as I have said before, extreme care must be taken in using this formula. I mention these two cases to show that after all the determination of the strength of the shafting is not quite the simple matter which the author appears to think it, and that after all the Registrys and the Board of Trade may, and I no doubt have, very sound reasons for adopting the particular formulæ which they use. The burden of the author's complaint appears to be the use of constants in certain formulæ, accompanying the Board of Trade and certain Registry Rules, which appears to the author to be a sufficient reason for his criticising them as merely "rule of thumb" rules.

Now, in a number of cases, it is almost impossible to deduce a satisfactory formula from purely theoretical principles, and in order to get results from which a formula may be based, in many instances an elaborate series of experiments have had to be carried out, the results of which have been plotted on paper and a curve drawn giving the average results of the tests. An equation is then found to fit the curve, the form of such equation being determined by the shape of the curve, which in many instances has several constants, but

Mr. Wilson as the equation expresses the law governing the strength of the particular piece of apparatus under test, it cannot be said in any way to be a rule of thumb.

I think the author might modify some of the expressions he has used, as it would render the paper more scientifically correct. In places it is a little misleading.

Mr. Flinn Mr. Hugo Flinn said—Before anyone who professes to have any real knowledge of the subject dealt with in the paper takes part in its discussion, I should like to say a few words of criticism of methods of criticism of the author's methods of criticism adopted by the last speaker. His principle seems to be that, because in the author's statement of his case technical terms have been used somewhat unusually, therefore the author's contention that there should be some reasonableness, some relation between the factors of the formulæ for calculating strength of shafts and the work they are intended to do, should be disregarded. It would be as germane to the issue to suggest that the punctuation of the written statement of a case should be taken primarily into account in weighing the merits of a case itself. We all quite clearly understood exactly what the author wanted to convey and that is quite enough.

It ought to be possible to construct a formula from a purely theoretical standpoint and to add to it factors of safety and other constants such as practical experience suggests, and yet leave a basis of calculation for so straightforward a thing as a marine engine shaft, which would be capable of being understood by plain men. I certainly, as an outsider, always believed that everything in relation to marine engineering was based on plain straightforward scientific principles, and the author has done a good work in bringing before our notice a series of formulæ for the calculation of the strengths of the most vital parts of marine machinery, which are not merely contradictory but apparently wanting in any scientific basis, and if his paper does anything to put this matter on a somewhat more reasonable footing he will have earned the gratitude of all "who go down to the "sea in ships."

Mr. West Mr. Henry H. West said—In the first place I wish to congratulate the author on his very interesting and useful paper.

I confess to a great deal of sympathy with him. I think we are entitled to know why Lloyd's and the British Corporation and the Board of Trade give us these rules and what they are based upon. I think it is our fair and proper due that we should have the information supplied to us. The inconvenience of several bodies, all of whom we may have to work under at the same time, having different rules that

are not harmonious with one another, is very great; and I think that if this paper induces the several authorities to meet together and to agree on some rules that would satisfy the Engineering public as being just and rational, and which all could adopt—and adopt with satisfaction to themselves—good results will accrue to the shipping trade. Mr. West

I agree that these rules as laid down have most probably been considered on first principles, and that there is a connection with such principles which, perhaps, is not immediately obvious, but I agree with the author that if these rules, as presented to us, do not commend themselves to our reason, we should, at any rate, be informed where our reasoning is wrong. I remember, a good many years ago, one of Lloyd's principal surveyors told me that for a triple expansion engine of about 160 pounds working pressure, the addition of the diameters in inches of the high pressure, intermediate and low pressure cylinders, and the stroke also in inches, dividing the sum by 14, would give, very approximately, the diameter of the crankshaft in inches. I found that in most cases it proved correct within a fraction of an inch. My own practice is to work out my shafts for myself according to what I call first principles, and then to compare them with Lloyd's Rule. If Lloyd's Rule asks me for less than my own, I stick to my own; if it asks me for more, then I take Lloyd's.

I think too much has been made of the author's use of phrases. I take it he has used ordinary colloquial language, and it seems to me hypercritical to object to his use of the word "stress" for "strain," and the like.

I thank the author personally for drawing our attention to this important subject and for the paper, which is of great value to the Transactions of the Society.

Mr. W. D. Kirkpatrick said—I think the Society is much indebted to the author for bringing the question of the classification, designing rules and regulations into prominence. Mr. Kirkpatrick

There is one rule not referred to which occurs in the Bureau Veritas Construction of Engines which would bear explanation. A formula is given for the diameter of the crankshafts of double, triple and quadruple expansion engines, and a note is added which states that for triple or quadruple engines the intermediate cylinders do not come into account in the formula. A casual examination appears to show that the intermediate cylinder or cylinders do not exert any turning moment on the crankshaft.

I can emphasise the author's remarks as to steering gears that there should be some regulation on supervision, although hard and fast

Mr. Kirkpatrick

rules might, owing to the great difference in the design of vessels, tend to prevent progress in this direction. With regard to steering gear, apart from the rudder itself, an incident of the unreported class which occurred some time ago to one of His Majesty's torpedo boat destroyers might be of interest. A progressive trial was in progress. The last mile (at full speed) was about to be run, when, standing in front of the main engines, I noticed the telegraphs were at "full astern." The engines were instantly reversed at full speed and the vessel stopped within 30 feet of a rocky shore. Steering gear! A split pin out of place! Had the engines not responded as quickly as they did, the vessel would have been crumpled up like a cardboard box, as the speed at which she was travelling was 30 knots per hour. This accident would not of course come under the notice of any of the Classification Societies, but serves to show what an important matter steering gear is.

Mr. Grundy

Mr. J. GRUNDY, in reply, said—I beg to thank the members of this Society for their hearty reception of my paper, and also to thank those gentlemen who have been good enough to take part in the discussion. Mr. H. W. Wilson took exception to some of the expressions, but this is immaterial, as it does not matter what phrase is used, my meaning is quite clear, and this is pointed out in a most unmistakable manner by both Mr. Hugo Flinn and Mr. H. H. West. I am much indebted to the latter gentlemen for their reference to this, as I endeavoured to make the paper perfectly plain, without using technical expressions. The large number of varying rules to be found do not bear out Mr. Wilson's assertion that it is not a simple matter to determine the strength of a shaft, but, on the contrary, owing to their multiplicity, they point to it being an easy matter. It is quite possible, as pointed out by Mr. Hugo Flinn, to have a formula for the strength of a shaft that could be easily understood.

Mr. Kirkpatrick did well in pointing out that some rules do not take into account the intermediate pressure cylinder. It is strange this cylinder should be left out of any calculation for shafting. Mr. West anticipated my case with regard to the rules, and in so doing he gave my views better than I could have done. I cannot do better than follow him and repeat that the rules are given to us and we are entitled to know the meaning of them, and what they are based upon, in order that we may know what we are doing. I protest against rules which it is impossible to understand. They are bad examples and it is quite time they were dealt with by the authorities.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

SIXTH MEETING—25TH JANUARY, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Commander HENRY BELAM, R.N., and Mr. WALTON S. POOLEY, as *Associates.*

DESIGN AND WORK OF HYDRAULIC PRESSING, STAMPING, FORGING AND SIMILAR MACHINERY.

BY F. W. STEELE.

WHEN the author was requested by our Honorary Secretary to read a paper at the Society's meeting, the difficulty was to choose a subject with which the writer is conversant which would be most instructive and interesting to the members.

In looking through the index of papers that have been previously read, there does not appear to be one on the subject with which the author proposes dealing this evening.

Probably there is no branch of the mechanical engineer's profession in which he is called upon to design and manufacture a class of machine and plant which is so varied in its application for different purposes as hydraulic pressing and similar machines, for instance—Baling, oil pressing, pipe making, bending, flanging, stamping, forging, tube and shell drawing, gun-cotton and cordite plants, &c.

The designing of a hydraulic press with its complete plant is a matter requiring careful consideration, especially in an installation running into thousands of pounds, as an example the large forging press installation at the Bethleham works where there is a hydraulic

press of 15,000 tons power, said to be the largest and most powerful forging press in the world. For this press, pressure water is supplied to two plungers which are placed side by side at a pressure of 7,000 pounds per square inch, the columns supporting the crosshead are 14 feet 6 inches apart, and the working height under the crosshead 17 feet 1½ inches.

There is also for forging hollow steel shafts a 5,000 tons press, and another of 2,500 tons capacity. Among the castings made there was the largest steel casting in the world for a 12,000 tons armour plate hydraulic forging press; the weight of the casting was 145 tons gross. The above indicates what the manufacturer may be called upon to produce.

DESIGNING.

It is essential that the installation should be so designed that the work to be done should be produced at a minimum of labour and cost.

Every part should be carefully considered so that the pattern-maker, moulder, smith, machinist and erector should have the minimum of labour in constructing it.

Complicated brackets, difficult forgings and machining is very often the cause of enhanced cost of production of the plant.

An important point is to see that the material used is distributed to the best advantage; the breaking strain of the material being known, the experienced designer knows the safe limit of stress to allow.

This very much depends upon the nature of the machine, that is to say, whether it is slow working or quick working, of the column type or open gap type. For instance, in an ordinary four column press with tables of cast iron 1¼ tons per square inch stress may be allowed in tension, and 2 tons per square inch in compression with the material to stand the usual test. In a gap machine such a stress would be much lower in tension and compression. In cast steel the stress is much greater, the tension and compression being the same, 5 tons per square inch for tension and compression in a column machine, and 3½ tons per square inch for open gap machines. It is not advisable to take these figures for all circumstances, as conditions vary with centres of columns and method of working, also steel by different makers vary in its ultimate breaking strain. The columns of a press are usually made of steel with a tensile stress of 28 to 32 tons per square inch, this being a good quality steel, easy of machining. When we exceed this, the material is of a harder nature and takes considerably more time to machine. The threads of a press should be

of the V instead of ⊔ shape, the V being as strong again as the other in shear, and another point the author would especially call attention to is to put a radius wherever possible if ever so small, thus considerably strengthening the part.

Let us now consider the press head, or base, and its relation to distribution of material. Assuming that the power of the press is settled, we have now to consider the method of load, is it a central, partly distributed, unevenly loaded, or entirely distributed load. This will determine the bending moment from which we shall arrive at the amount of material required to take the stress. The dimensions of the press may necessitate our making the press head as Fig. 1, Plate I, in which case the press head should be made with metal tapering from centre to ends to get the best distribution of metal consistent with strength, or as in Fig. 2. The box section of girder is the best form for getting a good distribution of material, the form Fig. 3 is sometimes made on account of the moulding or cores. This means a very bad distribution of material, as the tension member must be supplied, therefore the webs are made much stronger than necessary and the weight thereby increased.

Again, the depth of the girder is a most important matter to consider, greatest depth means greatest moment of inertia and least weight.

In the case of a press with the cylinder cast in one with table, Fig. 4, which is allowable in some cases; in addition to the press head being taken as a beam, due allowance must also be made for the bursting pressure as a cylinder, it is an important point to recollect. A beam will only take one duty, and each part must be separately dealt with for tension, compression and shear or any other force that may be applied. If the press head is made with loose cylinder, Fig. 5, the press head must be made strong enough for tension and compression and the cylinder for bursting pressure only. For bursting, the formula $\frac{P}{S} = \frac{t}{r}$ is sufficiently accurate, that is :—

P = Pressure.
S = Stress.
t = Thickness.
r = Radius.

Example, required the thickness of cylinder 20 inches inside diameter for a working pressure of 3 tons per square inch, say the tensile strength of material 36 tons, factor of safety 6, then $\frac{3}{6} = \frac{t}{10} = \frac{30}{6} = 5$ inches thick, or for exact calculation use "Lamè's" or "Patterson's" formulæ.

The flange of cylinder requires to be strong enough to take the shear, and of sufficient width for crushing strain, this latter point is sometimes neglected with disastrous results.

We have now considered press head, cylinder, base and columns, the nuts require to be strong enough to take shear. The ram is in compression. Gland taken as a beam and gland studs taken out for tension.

We have so far dealt with the column type of press. The open gap type of machine is usually adopted for hydraulic punching, shearing, forging and welding presses up to 300 tons power. It is sometimes made with loose head, Fig. 6 forming the cylinder, and bolted up to the main frame, the bolts *A* being of sufficient strength to take the tension due to load and the abutment *B* taking the weight and shear. This type of head is most often adopted in the vertical machine on account of the machine otherwise exceeding the bridge limit of the railway company; for foundry or other reasons, a much preferable way is to make the head as in Fig. 7, Plate I.

The body of machine must be strong enough to take the moments due to tension and compression.

Fig. *A* shows the section usual for cast iron bodies, as the tension members require in some cases to be as much as 8 inches thick and the webs are amply strong about $2\frac{1}{2}$ inches, the metal is gradually tapered down to prevent unequal cooling or contraction.

We have dealt so far only with presses of simple construction with single ram and with a moderate pressure (say) of 700 pounds to 2,240 pounds per square inch, and have not considered the method of pulling back the main ram. When a hand pump only is used the press ram in the undertype falls by gravity, or in the horizontal or overhead type a weight drawback is used for a long stroke, or powerful spring for short stroke ram, or hydraulic drawback. In presses exceeding 100 tons power the pressure adopted may be from 1 ton per square inch up to 4 tons per square inch, and the press may be made with one, two or three cylinders; in the two cylinder the full power must be utilized, in the three cylinder the pressure may be put on one, two or three cylinders at the will of operator, as work may require, the object in using the higher pressure is for economy in working and to make the plant as small as possible and reduce size of rams, pipes, valves, &c. Cylinders up to 1 ton pressure per square inch are usually made of cast-iron with hemp-packed glands, above this pressure of cast-steel or forged-steel with leather packings. If the leather is in the cylinder the latter should be formed as Fig. 8.

If the leather is on the ram the cylinder should be gun-metal bushed, the usual method being as Fig. 9, Plate I, the bush being forced in with hydraulic pressure and held in with ring at bottom with set pins.

In all cases a leather should work against gun-metal and not against cast-iron and hemp-packing against cast-iron.

The presses are also made water saving in several ways: in an overhead press the ram falling by gravity, in which case the drawback must be operated by a separate valve (not constant pressure), or in the undertype by rams taking up the crosshead and rams, the main cylinder being filled either through the exhaust or through check-valve from overhead tank, and in varying pressures the main rams are pushed up or down, as the case may be, by hydraulic pressure rams (constant pressure bringing them back) and when the die comes in contact with the work, the high pressure valves are automatically pushed over to pressure, putting on the intensified pressure or what pressure may be required.

VALVES AND PIPING.

Although the design of every part of a press is of importance, none is more so than the operating valves, these are generally the most vital portion of a press, a badly designed valve being a source of endless trouble and expense. In a slow working press for low pressures the valve is usually made of the screw down type, Fig. 10, or of the leather packed piston type, Fig. 11, or slide valve type. Beyond 1 ton per square inch, valves are made of the balanced mitre type with forged-steel bodies and heavy phosphor bronze fittings. In a large press of quick action and heavy pressure, where the valves and pipes are of large area, it is necessary for the valves to be hydraulically or fluid worked. There are several methods of doing this, either by pilot valves to release pressure before opening main valve, or by a separate valve, controlling a double acting cylinder with ram operating the levers of the main pressure and exhaust valves as in Fig. 12, or by pressure worked valves as in Fig. 13, the drawings of which with notes will make these clear. It is usual in a press cylinder for one pipe to serve between the valve and cylinder for pressure and exhaust, this is to some extent detrimental for quick action, the best plan is to have separate pipes from cylinder to valve for pressure and exhaust, in which case no pause or reversal of the current of water in the valve is required. Fig. 14, Plate I, illustrates the author's meaning.

VELOCITY OF WATER THROUGH PIPES AND VALVES.

The following table gives the velocity in feet per second at pressures from 700 pounds to 7,000 pounds per square inch which the water will require if discharged into the atmosphere through an approximately frictionless aperture. Velocities for intermediate pressure may be calculated from the formulæ.

Velocity in feet per second = $12{\cdot}19 \sqrt{\text{pressure}}$ in pounds per square inch.

In pounds pressure per square inch ..	700	1,500	2,000	3,000	4,000	5,000	6,000	7,000
Velocity in feet per second ...	326	472	548	670	772	862	944	1,020

With an accumulator pressure of 700 pounds per square inch the natural velocity (theoretically) is 326 feet per second. It is found in practice that not more than one-tenth of this can be obtained through the pipes and one-third through the valves to maintain the proper speed of the machinery.

APPLICATION OF PRESSURE AND METHOD OF WORKING.

The power applied to the ram in a press is a fluid by which a force exerted on a ram of small area is transferred to any member of such areas being in contact with the fluid which exerts the initial pressure.

According to the power of press and output demanded such will determine the motive power required, circumstances dictating whether the motive power shall be hand, electric, or steam.

Hand pump with single or double rams, the large ram filling the press and doing what work it can, and then the smaller ram finishing the operation.

Belt driven pumps, with rams of varying diameters to give various pressures where no accumulator is used, or equal diameter rams where an accumulator is used, electrically driven pumps, steam pumps of direct acting duplex type, or pumping engines, non-compound or compound surface or jet condensing, or low pressure water taken from power company's mains, and higher pressures put on by an intensifier hand operated or automatically worked in series to give various pressures.

In putting down pumps and accumulator it is necessary to prevent accumulator being over-pumped, or prevent the pumps continually running, and have in some instances automatic arrangements to stop and start the pumps at rise and fall of accumulator. For belt driven

pumps a deflecting and non-return valve is provided, so that as accumulator rises a valve is raised, and the pumps still running, merely circulates the water back to pump tank; on the accumulator falling the valve is closed and the pump again raises the accumulator; a non-return or check valve is placed between the pump delivery and accumulator cylinder (Fig. 15).

For steam pumping engines a valve is placed near the accumulator which is actuated by a tappet, the valve admits pressure on the rise of accumulator to a hydraulic cylinder on the steam valve of pumping engines, stopping the pumping engines and exhausting the hydraulic cylinder on the fall of accumulator, starting the pumping engines, or sometimes a throttle valve worked by chain from accumulator. (See Fig. 16, Plate I.)

AUTOMATIC STARTING GEAR FOR ELECTRICALLY DRIVEN PUMPS.

There are several methods by which the pump motor can be controlled from the accumulator, the following being perhaps the most satisfactory. (See Fig. 17, Plate I.)

A striker is attached to the accumulator in the most convenient position, as at *A*, set to strike the tappet switch *B* when the accumulator has described (say) within 9 inches of its stroke.

The automatic starting gear is of the solenoid control type, consisting of a solenoid main switch *C*, solenoid multiple step switch *D*, and four subsidiary solenoid switches *E F G H*. The cycle of operation is as follows:—

As soon as the tappet switch *B* is closed the circuit is made through the main solenoid switch *C*, causing it to attract its plunger and the current is then supplied to the shunt of the motor and also to the armature through the whole of the external armature resistance. Upon this main solenoid switch closing, a small current is supplied to the upper solenoid *D*, and its plunger is attracted and so rises slowly upwards. The speed at which the plunger moves can be adjusted within certain limits at the dashpot, when the lever has risen to the second contact the solenoid *E* is excited and its switch closed, short circuiting a portion of the external armature resistance.

The contact lever now moves on to the third contact and the second auxiliary solenoid *F* is energized, the connected switch closes, a further amount of resistance being cut out.

As the contact lever moves on to contact four and five, similar action takes place at solenoids *G* and *H*, the motor thus being gradually brought up to full speed. The pumps continue to supply

accumulator until striker opens tappet switch, cutting off current to solenoid switches which immediately open and stop motor.

BALING PRESSES.

These are familiar to all here, usually being of the undertype for compressing a loose material into a compact form for storage or shipment. There are many varieties of these supplied with one or more boxes, as the output may demand.

TUBE DRAWING PRESSES.

These are made of the horizontal type, either single ended, with annular drawback, or double ended, one ram drawing back the other ram by means of tie bars attached to the moving crossheads, so that as one tube is being drawn, the other tube is being stripped off the mandrill; they are made in powers of from 40 tons up to 1,000 tons for cold drawing brass, copper, and steel tubes through suitable dies.

SHELL AND CARTRIDGE PRESSES.

Many forms of these presses are made more often of the vertical type, the power and arrangement depending on the size of shell or cartridge case to be dealt with; these presses require to be very carefully designed and manufactured to ensure the walls of the shell being of equal thickness throughout. The presses are made from 50 tons for cartridge cases up to 2,500 tons for steel shells. For drawing shrapnel four operations are necessary, cupping, punching first and second drawings, these require powers of 80, 70, 450 and 600 tons for 6-inch shrapnel and less or more power according to size. Fig. 18, Plate I, illustrates a hydraulic press for cutting out, cupping out, flattening, indenting and heading cartridge cases up to 12 pounder (three inches diameter). This press (Messrs. Archdales) (Fig. 18) was designed to be worked with ordinary hydraulic pressure of 700 pounds per square inch from an accumulator when performing the lighter operations of cutting and cupping, and with an intensified pressure of $1\frac{3}{4}$ tons per square inch for the heavier operations of indenting, heading, &c. It consists of a steel cylinder *A* and ram *B* carried in an entablature *C* and supported by two steel pillars which also take the pressure and are firmly attached to the supporting base on which the die block *D* rests. To the ram is attached a cast iron crosshead guided by the pillars and prolonged on each side to take the lifting cylinders rams *E E*. Two detachable extractor rods *F F* are also carried by the crossheads when heading or similar operations

are being done, and carry by means of a smaller crosshead *G* an extractor rod *H* working centrally through the base.

Two cast iron cylinders *I I* (one on each side) are attached to the base, available for extracting the cases and returning the main press crosshead and ram.

The press is worked by two valves *J J* placed in a convenient position for the operator to see all movements, and governed by two levers with interlocking gear *K*, preventing a wrong movement being made, also provided with a check valve *L* to prevent the intensified pressure entering the general system of pipes. The various dies are carried in bolsters *M* on the base of the press, the corresponding punches *M'* being carried on the crosshead in a sliding block *N*, which allows of the punch being moved to one side in order to insert or extract a case during the various operations.

To obtain the higher pressure an intensifier *O* is provided, consisting of a lower vertical cylinder of cast iron, into which the accumulator pressure is admitted when desired, which acts upon an intermediate moving cylinder of steel and from thence passes the intensified pressure through an upper hollow ram of steel to top of the main press.

AUTOMATIC HYDRAULIC GUN-COTTON CARTRIDGE PRESS (WEST'S).

Fig. 19, Plate I, shows a hydraulic press arranged to work continuously, for pressing gun-cotton into cartridges of any required diameter, length and density; the material is placed in holes in the revolving table and is pressed into cartridges, which are delivered into trays, or on to a conveyor belt. Different diameters of cartridges are made by changing the liners in the tables, and the plungers on crosshead. These presses are made in all sizes, and the illustration shows a press arranged to make cartridges from $\frac{3}{4}$-inch diameter up to $2\frac{1}{2}$-inches diameter.

Referring to the Fig. *A* is a cylinder with double acting ram to which is alternatively admitted pressure water (from pressure mains) to top of piston for pressing and to the underside or annular space for returning the ram *B* and die *C*. The action of working is as follows:—*E* is a valve which is automatically controlled by the movements of the tappets rod *F*.

F is a double acting piston valve with constant pressure on the annular area, which by its movement admits pressure water to the top or underside of main cylinder by means of the pipe *E* to top of cylinder and *F* to underside of cylinder, *H* is the main pressure inlet

and *I* the main exhaust; the revolving table *J* is also automatically revolved at each operation by means of the movement of the tappet *K*. It is by such means as these that production is rendered less costly, and articles can be turned out in large quantities cheaply and expeditiously.

GUN-COTTON PRESS AND FORMING MACHINE FOR GUN-COTTON (BELL'S PATENT).

Manufactured by C. & A. Musker, Limited.

Fig. 20, Plate I, shows a machine for forming the pulped gun-cotton into required size and shape. *A* is a mould with perforated walls and open ends, contained in an air-tight chamber *B*; at the upper part a feed pipe *C* is connected and the lower end is provided with a removable perforated bottom *D*, to which is attached a connection *E* for an exhauster.

To exert pressure upon the gun-cotton two pistons *F F* fit the mould, moved upwards and downwards towards each other by rams *G G*; one of these pistons *G* has the feed pipe *H* attached to it, to allow the pulp to pass through, and the other carries the perforated bottom *I*. By means of suction and pressure, the air is extracted and the fibres of gun-cotton are uniform. The blocks being subjected to pressure and the air extracted, the blocks are given the required strength and density to prevent them, while being transferred from the forming machine, Fig. 20, to the hydraulic press, Fig. 21, from cracking and admitting air which would not be expelled by the final pressing.

GUN-COTTON PRESS.

Fig. 21, Plate I, shows a very powerful press of 1,500 tons power for pressing into blocks gun-cotton for shells, torpedoes, submarine mines, and other warlike purposes. Gun-cotton, although a waste product chemically treated, is a very explosive substance, and a press for dealing with the material must be very specially constructed, every portion which comes in contact with the gun-cotton in the pressing of the material must be of gun-metal. The press is of the horizontal double ended type with two cast steel cylinders *A*, rams *B*, and drawback cylinders and rams *C*, the main cylinders are contained in the entablature *D*, distance pieces *E*, or continuation of rams are attached to the main rams, the distance pieces requiring to be made of varying diameters for different sizes of gun-cotton blocks. On the

distance pieces *E* are attached water safety heads of gun-metal. *F* is a receiver in which the mould *A* from forming machine Fig. 20 is placed with the partly compressed gun-cotton, where it is subjected to the powerful pressure of $3\frac{1}{2}$ tons per square inch on the rams *B*, the pressing from each end giving the required density, the container *F* is hinged so that the mould *A* can be placed in the container or removed. The mould is in three sections to allow of the shell being taken out after pressing; several pressures are used in the press up to $3\frac{1}{2}$ tons per square inch. Length over all, 50 feet. Total weight, 110 tons. The accumulator was of special construction of the overhead weight case plunger type, so arranged that a pressure of 700 pounds per square inch, 1000 pounds per square inch, or 2,240 pounds per square inch, could be put on the press rams, two intensifiers giving the higher pressures. A large range of powers were thus arranged for giving the required density to any size of gun-cotton block up to 36 inches diameter.

The pumps were of the three throw belt driven type, driven from the line shafting.

Accessories for pulping the gun-cotton and an overhead crane with all motions of racking, cross traverse and longitudinal traverse, operated hydraulically, were also provided for raising the mould with shell or raising the hinged cover of container. Total weight of plant, 165 tons.

Fig. 22 shows a press for pressing the waste from punchings and shearing of scrap steel into bundles for export. A hundredweight of this loose material bound round with wire occupies a space of 10 cubic feet. When pressed into bundles in the powerful press it only occupies ·5 cubic feet and requires no bundling, the material being quite compact.

A is the box for material, *B* the pressing ram for compressing the material into a small space, and *C C* are two powerful side rams for putting on side pressure of 250 tons to reduce the bundle to required density; direct acting or annular drawbacks are used for the rams, a shutter worked by a double acting cylinder *D* allows the bundle to fall out for removal.

Upon the quantity of material to be dealt with per day depends the size of pumps and accumulator. The plant shown turned out 10 tons per day of 10 hours, with accumulator ram 9 inches diameter by 14 feet stroke and set of four throw belt driven pumps with rams $2\frac{1}{2}$ inches diameter, 18 inches stroke, and was constructed for a pressure of 1 ton per square inch.

FLANGING PRESS, WHEEL PRESS AND PLANT.

Fig. 23, Plate I, shows a hydraulic flanging press for flanging locomotive plates as shown; the press is of the undertype, with four columns, centres 9 feet 6 inches by 5 feet, it has one central ram *A*, 20 inches diameter by 45 inch stroke for flanging the plates, with central ram *B* 8 inches diameter by 45 inch stroke, four holding up rams *C C C C*, 6 inches diameter by 40 inch stroke, and two water saving rams *D D* for bringing the dies up to the work, the main ram filling by gravity from overhead tank, thus economising high pressure water; the whole of the tables were of cast steel and rams copper coated.

A 6-ton crane of the lifting jib type was provided for lifting the plates and changing the dies.

Fig. 24 shows the latest type of hydraulic press for putting loco. wheels on and taking them off their axles. It is of the single ended type and arranged for two pressures of 1,500 pounds per square inch and 2 tons per square inch, giving a maximum power of 300 tons.

It is of somewhat novel features, cylinders with rams and multiplying sheaves being arranged for raising the wheels and axles. For working the plant an accumulator of the weight case type was supplied with ram 16 inches diameter by 18 feet stroke, and a set of vertical three throw compound surface condensing pumping engines with 19-inch diameter H.P. cylinder and two L.P. cylinders 24 inches diameter all working 18-inch stroke, pump rams $3\frac{1}{8}$th inch diameter, 18-inch stroke.

COLD PLATE BENDER (MUSKER'S PATENT).

Fig. 25, Plate I, illustrates a machine constructed by Messrs. C. & A. Musker, Limited, for bending plates cold from 2 feet diameter up to any diameter, the machine illustrated was for a working pressure of 1,000 pounds per square inch. The rams are 16 inches diameter by 15-inch stroke, giving a total power of 150 tons on the plate, and capable of bending plates 8 feet long $\frac{3}{4}$ inches thick. The press is so constructed that the parts are as few as possible.

The main frame *A* forming the bedplate, beam for cylinders and tension member for the removal bolts *B*.

The cylinders *C C* are provided with positive stops, the stroke of main rams being regulated to an infinitesimal amount by means of the hand wheel *D*. A moving girder *E* is pushed forward on to the plate, the girder being provided with a loose die with concave face, the outer beam *E* being convex; the amount of curvature on the plate depends upon the amount of travel of the moving beam *E*; a drawback cylinder

G with constant pressure or automatic water saving is provided as shown. After the plate is bent the tie bolts *B* are raised to allow of the plate being removed, automatic gear is fitted to feed the plate through the dies so that the minimum of labour is required, the press is also used for a variety of other purposes, appliances having been fitted for bending and joggling; the heaviest tools are of 500 tons power for 2-inch plates.

THREE-MOULD HYDRAULIC FLAG PRESS (MUSKER'S PATENT).

Fig. 26, Plate I, shows a hydraulic three-mould press for making flags from clinker and cement, or from granite chippings and cement. The press is also used for making bricks, channeling, kerbs, window sills and for many other purposes, the heavy pressure of 500 tons giving the material the consistency of stone. The output from the press as a maximum is 60 slabs per hour or 600 bricks per hour. The material is mixed in a mill, and then fed to the moulds of the press, these are 3 feet by 2 feet, 2 feet by 6 inches by 2 feet, or 2 feet by 2 inches, and the flag when finished $2\frac{1}{2}$ inches thick.

The press is of the vertical two column type, and provided with three revolving moulds, so that filling, pressing and discharging is taking place simultaneously, a set of three throw pumps deliver the pressure water on the press ram direct, the rams being of varying diameters for taking up the clearance, filling the press cylinder quickly, and putting on the final pressure of one ton per square inch.

There is only one valve for operating, and the whole arrangement is of the simplest character. Referring to the Fig., *A* is the cylinder of cast steel, *B* the ram, *C* the pressing die, *D D D* the moulds, *E* the perforated plate to allow the moisture to be expelled, *F* the carrier for moulds *D D D* which are revolved around the column *G* by means of the friction cone, driven by means of the bevel gearing *H* and belt pulley *I*, a lever *J* being pulled down to start the carrier *F* rotating with the moulds *D D D*, the lever being automatically returned. The table *K* is provided for the perforated plate to rest on, while the material is being filled in the mould and pressed. When the moulds arrive at the discharging point in table, the perforated plate falls away, the flag is discharged and carried away for storage.

Where other hydraulic machinery is required in connection with the press an accumulator is provided, but this is quite unnecessary and entails extra cost and upkeep, if the plant is required only for the purpose and similar work as stated. The following tables, supplied by the makers, give approximate cost, &c., of production.

APPROXIMATE COST OF MANUFACTURE OF ARTIFICIAL PAVING SLABS MADE FROM CLINKER AND CEMENT.

Based upon an output of 20,000 *square yards* $2\frac{1}{2}$ *inches thick.*

20,000 *square yards* = 2,500 *tons.*

	£	s.	d.
550 tons Cement at 33s. per ton	907	10	0
1,700 tons Clinker, crushing same at 1s. 6d. per ton ...	127	10	0
Wages of 3 men at Machine, Mixer, and carrying out at 20s. to 25s. each, and 2 men stacking and loading at 16s. to 18s. each, say £5 per week	250	0	0
Paper, Oil and Sundries	100	0	0
Rent of Premises and Power for Pumps and Mixer.. ...	100	0	0
Interest on Capital	60	0	0
Repairs and Depreciation of Machine and Buildings	100	0	0
	£1,645	0	0

= 1/7·6 per square yard.

APPROXIMATE COST OF MANUFACTURE OF ARTIFICIAL PAVING SLABS MADE FROM GRANITE CHIPPINGS AND CEMENT.

Based upon an output of 20,000 *square yards* $2\frac{1}{2}$ *inches thick.*

20,000 *square yards* = 2,250 *tons.*

	£	s.	d.
550 tons Cement at 33s. per ton	907	10	0
1,700 tons Granite at 10s. per ton	850	0	0
Wages of 3 men at Machine, Mixer, and carrying out at 20s. to 25s. each, and 2 men stacking and loading at 16s. to 18s. each, say £5 per week	250	0	0
Paper, Oil and Sundries	100	0	0
Rent of Premises and Power for Pumps and Mixer ...	100	0	0
Interest on Capital	60	0	0
Repairs and Depreciation of Machinery and Buildings ...	100	0	0
	£2,367	10	0

= 2/4·4 per square yard.

[Please note that each 1s. per ton saved in the price of granite will mean a reduction in the cost of working of 1d. per square yard.]

FORGING AND WELDING PRESSES.

Fig. 27 and Fig. 28, Plate I, illustrate a type of open gap press largely used in locomotive and wagon works for stamping and welding, the open gap type machine allows the workman to easily manipulate his work and gives ready access to the dies for adjustment or removal; these presses are made from 20 tons upwards to 300 tons, they are made with either one vertical pressing ram, one horizontal ram for upsetting, and also with bottom ram.

Referring to Fig. 27 the press is shown operated direct from the mains supplied by an accumulator and operated in the usual manner by a piston valve for each cylinder.

A is the main frame, *B* the vertical cylinder, and rams *D* the horizontal cylinder, and ram *E* the bottom cylinder and ram, constant pressure being on the drawback rams.

Fig. 28 shows the press constructed for water saving, the main ram falling by gravity, the cylinder filled from an overhead tank, and pressure put on by operating valve when it reaches the work, the drawback cylinder being also operated by a valve for pressure and exhausting.

Fig. 29 shows the press automatic water saving, to the main ram *A* (or crosshead if two push down rams are used), a piston rod is attached as shown with double acting piston working in a bored cylinder *B*, constant pressure being on the underside of piston for pulling back the main ram, pressure is admitted by means of an operating valve *F* to the top of cylinder *D*, pushing the main ram downwards, the cylinder *A* at the same time being filled with water from an overhead tank, the die *E* thus being brought on the forging. Valve *F* fluid worked with cylinder *G* for constant pressure, keeping the valve *F* over to exhaust, and cylinder *H* for admitting alternatively, pressure water and exhausting the pressure in the pushdown cylinder; in the downward movement, the pressure in falling is only that due to friction of the moving parts, when a further resistance is set up, the pressure then becomes increased equal to the resistance, and the pressure water in top of cylinder *H*, connected to top of pushdown cylinders, becomes equal to the pressure caused by resistance, and the cylinder *H* having a larger area than cylinder *G* with constant pressure, the valve *F* is automatically pushed over, admitting high pressure water to the main ram and cylinder *A*. The small operating valve *C* being moved to exhaust, the cylinders *A* and *B* are exhausted.

These presses are also made to work automatically, Fig. 30 and Table adjoining gives some of the classes of work done and powers used.

LIST OF ARTICLES MADE UNDER HYDRAULIC PRESSES

AT GREAT WESTERN RAILWAY COMPANY'S WORKS.

Articles	Cat. No.	Press tons	No. of rams used
Buckles, Spring, all classes	—	100	2
Buckets, Safety	—	100	1
Brackets, Pawl, E.S.B.	—	50	1
" Block Hanger, E.S.B.	—	100	2
" " Standard... ...	6	100	2
" Comer Car and Wagon	25	75	1
" Diagonal Car and Wagon ...	26	100	2
" Bolster Timber Truck	21 and 22	100	2
" Stanchion Sleeper Wagon ...	20	100	2
" Stepboard T Long and Short ...	—	100	2
" " L " " ...	—	25	1
" " Diagonal	—	50	1
" Side Body	23	100	2
Cradle, Standard	27 and 28	100	2
Cylinder Covers, Top and Bottom 18 and 22 inches	48 and 49	200	2
Carriers, Buffing Spring	—	75	1
Guards, Safety...	41	100	2
Guides, Buffer Standard	19 A	100	2
Head Stocks, Motor Car	—	200	1
Irons, Leg, Cranked and Straight	—	50	2
Lamp Tops and Bottoms	38 and 39	75	2
" Rings	40 and 50	100	2
Manhole Covers and Rings for Water and Oil Tanks	17 and 18	200	2
Mangers, Large and Small	—	200	1
Plates D Bar	16	100	2
"	12	100	2
Rods D Bar, Intermediate	—	100	2
" 20-ton Standard Locomotive...	—	100	2
Rods, Tie Cranked 15¾ and 16¾ inch ...	—	P 100 B 25	2
Rings, Mansell	—	50	1
Store Trays	—	100	1
" Tops	—	50	2
Stops, Door Standard and 20 ton Loco. ...	15	50	1
" Spring, all classes	14	50	1
Stop Blocks	—	100	2
Shoes, Buff Standard and Carr	24A and B	50	2
Stanchions, T Steel, all classes	—	100	1
Shoes, Spring	4	100	2
Washers, Wheel Standard and 24 in. × 1 in.	—	200	1
Cross Bearers Motor Car	—	200	1
Invoice Boxes	3	25	1

HYDRAULIC FORGING PRESSES.

In presses of large power, say of 500 tons and upwards, it is essential that every part should be extra strong and rigid, and all parts with a low stress. The load may not always be central on the work, for which contingency the columns are usually proportioned on each side to take three-quarters the load, with very deep guides on the crosshead for side strains.

In presses of large calibre the entablature and base are often built up of cast steel girders joggled and bolted together, or with steel hoops shrunk on over snugs to take any side stresses. The presses are operated in different manners, one method being to have a steam accumulator for operating the lifting cylinders, and a set of three throw hydraulic pumping engines for pumping direct at a pressure of three tons per square inch into the press cylinder, the main ram falling by gravity, and filled with water from an overhead tank. With the pumping engine system, the steam consumption is more economical than with direct steam drivers. In a large forge works this is of not such great importance, as the waste gases from the heating furnaces are utilized for generating steam, probably for which reason the steam hydraulic press is largely used, this type also having the advantage in first cost. A description of its working may be interesting.

Such a press is illustrated in the engineering paper advertisements by the Darlington Forge & Co., drawing down a forged steel shaft, 55 feet long, 22 inches diameter, from a 60-ton ingot, which measured 60 inches across the flats.

The squeeze is applied by means of a steam-driven intensifier. The hydraulic cylinder of the intensifier is connected by a pipe to the cylinder of the press and the pipe and the two cylinders are kept filled with water from an overload tank through a valve which opens downwards to admit water from without, and closes against any pressure from within the cylinders. The area of the steam piston and that of the ram of the intensifier are so proportioned to each other that a pressure of steam produces a pressure 3 tons per square inch on the water above the forcing ram. To squeeze the forging, the workman depresses a hand lever, which moves a valve admitting steam below the piston of the intensifier, causing the forcing ram to drive the water into the cylinder of the press, the ram and crosshead is thus moved downwards. By raising the lever steam escapes from below the piston of the intensifier, when the piston and ram fall by gravity. The lifting of the moving head of the press is actuated by

two cylinders on top of press; in this press steam instead of water is used to do the lifting, the admission of steam to the lifting cylinders being controlled at will by a small three way cock, which enables the press to be worked in two distinct ways.

In the usual method of working, the pressure of steam is maintained continuously below the pistons of the lifting cylinders, thus holding the head up until steam is admitted below the piston of the intensifier, which overcomes the pressure of the steam in the lifting cylinders and drives it back into the boiler. On again releasing the steam from below the piston of the intensifier the lifting pistons regain their power and force the water back into the top of the intensifier, but as the quantity contained in the pressing cylinder and intensifier with their connecting pipe remains constant, the moving head of the press rises and falls through a distance due to the influence of the pressing and lifting cylinders. These prevail alternately one over the other, the rise and fall between the two fixed points being in accord with the movement of the workman's hand, thus squeezing the forging and permitting it to be moved along after each stroke ready for a fresh squeeze to be taken on a new part. If the normal stroke of the crosshead is insufficient it can be made to travel through a second and lower interval by merely turning the three way cock. This shuts off the constant supply of steam below the pistons of the lifting cylinders, with the result that the head remains stationary and water flows in from the overhead tank, and fills the vacant space left by the forcing ram of the intensifier. Then, as soon as steam is admitted below the piston of the intensifier, the press head descends through a second interval. This action may be repeated until the whole available stroke of the press head is used up, or until the material under treatment offers such resistance that it must be moved into a new position for another part to be squeezed.

When working the press in either of the above ways, all the workman has to do to lift the head sufficient for the forging to be turned over, is to raise his hand into a higher position, opening a valve which allows some portion of the water to escape, admitting steam below the lifting pistons. The head will then rise until the operator puts the lever controlling the press into the higher position, the head remaining stationary while the forging is arranged for another squeeze.

It will be observed this press requires no other supply of water under reduced pressure.

DISCUSSION.

Mr. G. E. Snoxall said—I congratulate the author on his excellent paper, first, on account of its great value to engineering generally, and second, because it is very refreshing to some of us old stagers to find that electricity does not occupy a prominent part in the paper itself. For the purposes specified in the paper, hydraulic pressure is certainly the most convenient in application and economical in maintenance of any form of transmission of power.

On page 100 the author refers to packed glands. When I was dealing with hydraulic work we generally used to make these strong enough, with a fairly low factor of safety, to stand the whole pressure on the cylinder without having to put it in an expensive press to hold the ends on. This is one matter which is sometimes overlooked and may cause considerable trouble in the shops.

On page 101 the author mentions that hemp-packing should work against cast-iron. I suppose what he means is that it is not necessary to have gun-metal working in hemp-packing.

With regard to accumulators, there is one very small fixture, and that is the safety valve on top of the accummulator, so that if anything happens, you have the safety valve coming into operation and preventing disastrous results.

Mr. F. E. Cooper said—What few remarks I have to make must be from the point of view of the user of hydraulic machinery and not from the manufacturing point of view.

I was very much interested to see, on page 110 of the paper, the costs of the manufacture of artificial slabs. It is no secret, of course, that the Liverpool Corporation have two of the machines described, and I am glad to say they give very satisfactory results. The 20,000 yards which the author puts down is below the mark so far as the Corporation is concerned. I think we turned out 25,000 yards last year.

The clinker from the Refuse Destructors is what we use, crushed to pass through a $\frac{3}{8}$th-inch riddle; the figure of 1s. 7·6d. per square yard is rather below what we could manufacture them at, as we make slabs 3 inches thick as well as $2\frac{1}{2}$ inches thick, but the figure gives a fair notion of what you can turn them out for. The 3-inch slabs are a very much bigger slab than those the author refers to on page 109.

Mr. Cooper

There is one thing which has occurred to me ; perhaps it is scarcely an engineering point. The author has dealt with the large side, the infinitely great, but there are quite as many examples of the infinitely small that we use every day—paper fasteners, steel pens, &c., all of which are produced by a stamping process, and the manufacture of which must have necessitated an immense amount of ingenuity, almost greater perhaps than for the larger articles dealt with by the author.

Mr. Steele

Mr. STEELE, in reply, said—I have not very much to reply to, although I thought I had given a good many openings for discussion.

When I wrote the paper, it was my intention to give a paper that should be instructive to those who are not just in our branch of the profession.

With regard to what Mr. Snoxall says, it is sometimes best for testing purposes to make the gland studs strong enough to withstand the pressure.

It is not essential for hemp-packing to work in gun-metal, but a leather should, as the cast-iron oxidizes and cuts the leather.

With regard to the safety valve, I did not mention this, although it is obvious that there ought to be a safety valve, as also drain cocks and other details not particularly referred to.

With regard to the press for pressing up the scrap steel punching and shearings, the loose material takes up about 10 cubic feet, and when pressed half a cubic foot, saving an enormous amount of money in shipment. This material is the waste from cans and such like articles, the tin is extracted and is a very valuable product, being almost pure ; the bundles are exported to the Continent and come back to us in some other form or article.

With reference to the figures given for the manufacture of slabs, they are supplied by the makers, who, I know, have gone carefully into them, and rather over estimated than under estimated the cost of production.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

SEVENTH MEETING—8TH FEBRUARY, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

The following gentlemen were duly elected to the Society, viz. :—Messrs. LLEWELLYN FOSTER, R. E. GIBSON, and S. H. CROKER, as *Members;* and Mr. GEORGE L. DAVIDSON, as a *Student.*

FLOW OF WATER IN PIPES, CHANNELS AND RIVERS.

BY THOMAS DUNCANSON, M. Inst. C.E.

THE paper to be read to-night is largely the result of the persistence with which our President in his anxiety to fill up his programme for the Session kept urging upon the author what he conceived to be his duty towards the Society.

The subject chosen—the flow of water in pipes, channels and rivers—is one in which the author has taken a life-long interest, and deals with a question which, viewed as he proposes, has not received much consideration in its proceedings. The very valuable papers by Dr. Hele-Shaw on experiments on the flow of water and on fluid motion, although on hydraulic subjects, deal with an entirely different and probably a more interesting aspect of the question. What it is proposed to do to-night is to place before the Society a survey, necessarily rapid and incomplete, from its brevity in proportion to the extent of the subject, of the leading formulæ proposed for calculating the discharge of pipes, channels and rivers with a comparison of some of the experimental data on which these formulæ are based, together with some observations as to the present position of the subject.

Although founded on mathematical reasoning, practical advancement in hydraulic science has, as in most branches of engineering, been dependent chiefly on the careful observation and application of

experimental results and those workers who have either experimented carefully themselves or known how to reason from and carefully apply the experiments of others are the men who have enabled progress to be made.

The formulæ which it will be possible to touch upon to-night are those expressing the laws which govern the relations between the mean velocity, slope or hydraulic gradient, hydraulic mean depth and condition of the surface of any channel for conveying water, uniform flow being assumed to have been set up at the commencement of the length of channel under consideration.

The principle underlying the formulæ for the discharge of pipes, channels and rivers are practically identical, the difference lying in the application of coefficients, and in the general and historical glance at the subject the three classes will be considered together.

GENERAL AND HISTORICAL.

It may here be convenient, in order to prevent confusion, to define clearly the notation to be used through the paper. All dimensions used are in English feet.

The symbols which will be used are :—

(1) s = sine of the inclination $= \frac{h}{l} \frac{\text{head}}{\text{length}}$ = the inclination of the hydraulic gradient in pipes or the surface slope in channels and rivers.

(2) r = hydraulic mean depth.

$$= \frac{A}{P} = \frac{\text{area of section of stream.}}{\text{wetted perimeter.}}$$

(3) C = The coefficient in the Chezy formula.

(4) $\triangle$ = The condition of the wetted perimeter;

$\triangle_0$ representing the surface of fine cement;

$\triangle_{10}$ representing the surface in the case of rivers and canals in bad order with weeds and detritus in beds, intermediate values being represented thus $\triangle_1$, $_2$, $_3$, &c.

(5) v = mean velocity in feet per second.

(6) g = gravity 32·2

(7) d = diameter of pipes.

(8) n = coefficient of roughness in Ganguillet and Kutter's formula.

(9) a, b, k, m, various constants described in connection with each formula referred to.

Although the Romans and the Moors had some knowledge of the subject the development of modern hydraulic theories dates back only to the end of the 16th century.

Galileo, Torricelli, Guglielimini and others during the 17th century and the first part of the 18th century contributed a large quantity of mathematics, but not much enlightenment to the question of the flow of water. Couplet early in the 18th century seems to have been the first actually to make experiments, and Chezy towards the close of the same century produced the well-known formula which bears his name, and which with some modifications has formed a basis for most of the formulæ in use. This formula takes the form

$$v = C\sqrt{rs} \qquad (1)$$

Dubuat, also an experimenter, produced shortly afterwards his very cumbrous formula. He found that to meet the various conditions met with, C in the Chezy formula must vary, and his formula is arranged so that C increases as the velocity and also as the hydraulic mean depth increases. Dubuat's formula is

$$v = 88{\cdot}5 \frac{\sqrt{r} - 0{\cdot}03}{\sqrt{\frac{1}{s} - Hyp.\ Log.\left(\frac{1}{s} + 1{\cdot}6\right)} - {\cdot}089\left(\sqrt{r} - 0{\cdot}03\right)} \qquad (2)$$

One of the greatest stumbling blocks to progress towards a right solution in the early days was Grandi's theory that when water flows in a pipe or channel bed the surface on which it flows and the hollows in that surface are covered with a layer of fluid which may be looked upon as the real surface which encloses the fluid in motion. So that, under this theory, the condition of the surface over which water flows would have only a slight effect on the velocity obtained under any given conditions. It must be admitted that looking at the matter without making any actual tests there would appear to be a fair amount of reason to be adduced in favour of this view. The velocity throughout any section of a stream varies continually, being greatest near the centre, relative movement between the different films of water is therefore continually taking place, and it was probably not unnatural for those hydraulicians who contented themselves with mathematics and did not devote much time to experiment to accept this view.

Early in the 19th century Prony produced his formulæ founded on Coulomb's experiments on the rotation of discs, which took the form

$$v = \left(\frac{rs}{b} + \frac{a^2}{4b^2}\right)^{\frac{1}{2}} - \frac{a}{2b} \qquad (3)$$

With the values of a and b he adopted these worked out, put into the form of the Chezy formula.

For pipes $\quad v = 97\sqrt{rs} - 0{\cdot}08 \qquad (4)$

and for channels $\quad v = 103\sqrt{rs} - {\cdot}236 \qquad (5)$

This formula, as well as Dubuat's, involves the condition that with very small values of r and s there might be no motion whatever.

Prony was followed by Eytelwein, D'Aubuisson and Weisbach, who used the same form of formula as Prony, but slightly altered the coefficients. A formula attributed to Eytelwein and Young very commonly used early in the 19th century gives $\frac{11}{10}$ of the mean velocity in feet per second as a mean proportional between the hydraulic mean depth and the fall in two miles in English feet. Adapted to the Chezy formulæ this becomes for channels

$$v = 93{\cdot}42 \sqrt{r\,s}. \qquad (6)$$

Darcy, and Bazin, his assistant and successor, about the middle of the 19th century were the first to conduct really careful experiments on an extensive scale, and their researches went far to place hydraulic formulæ on a correct basis. They experimented on the flow in channels and pipes and ascertained that the coefficient in the Chezy formula varies with the hydraulic mean depth, and also to a very considerable extent with the nature of the surface of the bed of the pipes or streams under consideration. Their settlement of this latter point finally disposed of Grandi's theory. Darcy and Bazin did not make many experiments in which the inclination is varied, and the chief defect in the formulæ they derived from the results of their experiments is their neglect in allowing sufficiently for this variation.

Darcy's formula for pipes was $v = \left(\dfrac{1}{a + \dfrac{b}{r}}\right)^{\frac{1}{2}} \sqrt{r\,s}.$ (7)

in which for new cast iron $a = {\cdot}000{,}077{\cdot}2$

$b = {\cdot}000{,}001{\cdot}6.$

This equation was adopted, with some slight modification, by Professor Rankine, in his work on Civil Engineering, and likewise by Professor Unwin in the form

$$v = \left\{\frac{2g}{{\cdot}005\left(1 + \dfrac{1}{12\,d}\right)}\right\}^{\frac{1}{2}} \sqrt{r\,s}. \qquad (8)$$

From the first part of the latter half of the equation C is obtained.

This coefficient varies with the variation in the diameter from 88 for $1\frac{1}{2}$-inch pipes to 113·2 for 60-inch pipes.

For channels they adopted the form

$$v = \left\{\frac{1}{a\left(1 + \dfrac{b}{r}\right)}\right\}^{\frac{1}{2}} \sqrt{r\,s} \qquad (9)$$

the coefficients a and b varying with the condition of the surface of the channel.

	Values of		Equivalent values of C in Chezy formula			
	a	b	$r = 1$	$r = 2$	$r = 10$	$r = 75$
λ_1 Very Smooth Walls ...	·000045	0·10	140	144	147	148
λ_4 Fairly " ...	·000058	0·23	118	124	129	131
λ_6 Rubble Masonry Walls	·000073	0·82	87	98	112	113
λ_{10} Earth Walls	·000083	4·10	48	62	92	105

Messrs. Humphreys and Abbott, in about 1860, carried out a very extensive and careful series of experiments on the flow down the River Mississippi. As the result of these experiments, they proposed a formula in which the velocity varied as the fourth root of $r\,s$. As, however, some of the experimental determinations of s were for such falls as a quarter of an inch in a mile, it is obvious that not much reliance could be placed upon them. The ordinary errors of levelling are often greater than the total fall observed, besides in a river of the breadth of the Mississippi greater variations than this might easily be found on the opposite side of the river, and the use of the fourth root of s has not been continued.

In 1869, Messrs. Ganguillet and Kutter published their work on Hydraulics which was translated into English by Mr. Louis d'a Jackson in 1876. They submitted a formula, which transformed into the Chezy formula, makes C vary with the roughness of the surface of the bed through which the water flows (a condition for small channels of great influence), and with the variation in slope and in hydraulic mean depth. They considered the experiments of Darcy and Bazin, those of Humphreys and Abbott, and combined with these certian experiments of their own.

Unfortunately they adopted the two tests of Messrs. Humphreys and Abbott with low inclination, to which reference has already been made, and as a consequence their coefficients for very low inclinations and large hydraulic depths are higher than many authorities consider correct.

One peculiarity of the coefficients given by their formula is that up to a hydraulic mean depth of about 3 feet, C increases with increase in s but when r is greater than 3 feet C diminishes when s increases.

In Appendix III will be found tables of C calculated from this formula which shows this peculiarity. For channels with surfaces

plastered with pure cement when r exceeds 1 foot the high coefficients given by the formula are not justified by any reliable experimental data.

Their formula is the Chezy formula with the value of C varying in accordance with the following somewhat complicated expression :—

$$C = \frac{a + \frac{k}{n} + \frac{m}{s}}{1 + \left(a + \frac{m}{s}\right) \frac{n}{\sqrt{r}}}$$

a K and m are constant, and n a coefficient of roughness varying with the roughness of the surface. a k and m are respectively in English measures 41·6, 1·811 and ·00281, and n varies from ·009 for well planed timber to ·035 for rivers and canals in bad order. Substituting the value of the coefficients above given the expression becomes

$$C = \frac{41{\cdot}6 + \frac{1{\cdot}811}{n} + \frac{{\cdot}00281}{s}}{1 + \left(41{\cdot}6 + \frac{{\cdot}00281}{s}\right) \frac{n}{\sqrt{r}}}$$

they divided the surfaces in the case of channels and rivers into the eleven following classes :—

FALL 1 FOOT IN 1 MILE.

		Value of n	Corresponding value of C	
			$r = 1$	$r = 2$
$\triangle_0$	Well-planed Timber...	·009	171	189
$\triangle_1$	Plaster in Pure Cement	·010	152	169
$\triangle_2$	Plaster in Cement, one-third Sand...	·011	137	154
$\triangle_3$	Unplaned Timber	·012	133	149
$\triangle_4$	Ashlar and Brickwork	·013	114	129
$\triangle_5$	Canvas Lining	·015	96	110
$\triangle_6$	Rubble	·017	83	96
$\triangle_7$	Canals in Firm Gravel	·020	69	81
$\triangle_8$	Rivers and Canals in perfect order...	·025	53	64
$\triangle_9$	Ditto in moderate order	·030	43	53
$\triangle_{10}$	Ditto in bad order, encumbered with weeds, stones, &c.	·035	38	45

The finding of C from this expression is a somewhat laborious operation, although Messrs. Ganguillet & Kutter, Mr. Jackson and others, have done their best to simplify the calculation by the

production of tables and diagrams. As a result the velocity in any assumed case in the classes of surface may be determined to three places of decimals or more with every appearance of accuracy. The accuracy is, however, only apparent. The judgment must be used to determine which class the surface in question belongs to, and it is quite possible that it might be considered desirable to adopt an intermediate value for the coefficient. It appears therefore to be as accurate and certainly much simpler to select a value for C directly from a suitable diagram and avoid all the complications necessary for the calculation of C from such formulæ.

The next notable contribution to hydraulic formulæ came from America, where Messrs. Fteley and Stearns of Boston, U.S.A., carried out very careful experiments in the flow in the Sudbury Conduit for the supply of Boston. Messrs. Fteley and Stearns proposed the formula

$$v = 127\, r^{\cdot 62}\, s^{\cdot 5} \qquad (12)$$

to suit their experiments on the Sudbury Conduit.

Mr. Santo Crimp, in a paper read before the Institution of Civil Engineers (Vol. CXXII. 198), has proposed for flow in sewers the formula

$$v = 124\, \sqrt[3]{r^2}\, \sqrt{s} \qquad (13)$$

which in his view was a practical working formula for sewers and iron pipes founded on Darcy and Bazin's experiments.

In 1903, Messrs. Saph and Schoder read before the American Institution of Civil Engineers a paper on experiments in the flow through pipes of small size, principally of brass from $\frac{1}{10}$ inch up to 2 inches diameter, and galvanised iron pipes from $\frac{1}{4}$ inch to 1 inch.

Their experiments have the appearance of having been carried out with care, but probably owing to the small size of the pipes experimented on there are considerable discrepancies in the results. The writers of the paper strongly urge the desirability of using a constant coefficient and that the exponents of s and r should have other values than $\sqrt{}$

The formulæ they finally propose are, however, so vague that the author will not repeat them here.

Mr. Saph, however, later proposed the formula

$$v = 174\, r^{\cdot 67}\, s^{\cdot 54} \qquad (14)$$

The author has now placed before the Society the chief formulæ which have been proposed for determining the mean velocity in pipes, channels and rivers. The list shows that very considerable difference of opinion has existed and still exists as to the most accurate formulæ.

The author very strongly supports the view that the proper method is the adoption of a variable coefficient in the Chezy formula $v = \sqrt{r\,s}$. The Chezy formula is based on the theory that the motion of water in a channel is analagous to that of a body running down an inclined plane and the velocity is assumed to vary as the square root of the fall and of the hydraulic mean depth. As previously stated, most of the formulæ which we have considered are based upon the Chezy formula, and in relation to it may be divided into three classes.

(*a*) Those in which C remains constant.

(*b*) Those in which C is variable and is determined from a formula which takes into consideration the roughness of the surface and the hydraulic mean depth and sometimes the slope.

(*c*) Those in which C is constant, but an exponent other than the $\sqrt{}$ is used so as to enable the formulæ to fit in with the observed experimental results.

The experimental results show that formulæ in the (*a*) class can only be applicable to particular cases.

In the (*b*) class the necessity for calculating C can be avoided by the use of such diagrams as are placed before the Society enabling a suitable coefficient to be determined by inspection for use in each case, thus saving trouble in calculation and reducing the risk of error, and this method the author prefers.

In the (*c*) class the formulæ given show a great difference of opinion as to what values should be assigned to these exponents, and it is impracticable to obtain a value which is applicable to all classes of pipes, channels and rivers.

Although with a table of logarithms there is no serious difficulty in working the necessary calculations, yet there is some increased trouble and certainly greater risk of error than where the $\sqrt{}$ is used as the exponent, and besides, it is not practicable to attain that general check over a series of calculations which is practicable when the whole of the cases under consideration have a simple relation to each so that they can be checked by a glance; the author therefore prefers the method suggested above.

Another advantage of this method is that by plotting on the diagram the results of the experiments on which the diagram is based it is possible continually to keep under one's observation the relation between the experiments and the conclusions deduced from them, and so to ensure that the coefficient selected in any particular case is based on a true similarity in the conditions.

It is necessary now to consider the experimental data on which these various formulæ have been founded and by which it is possible to check their accuracy, and it may be said at once that there is room for a greatly increased number of really reliable experiments to enable the various points still unsettled in hydraulic formulæ to be accurately dealt with.

The existing formulæ and experiments are sufficient to enable useful working results to be obtained in most cases if used with judgment, hut there are quite a number of points which require clearing up, and more data is required to enable this to be done satisfactorily.

FIRST AS TO PIPES.

The diagram *A* (see Plate II) shows in dotted lines the observed coefficients of most of the important experiments made on pipes over 3 inches in diameter, the results of actual experiments being shown by dots. The coefficients for $1\frac{1}{2}$-inch pipes are from tests made by the author with great care. From some tests he had made on pipes of larger diameter he had been sceptical as to the amount of variation found by Bossut, Darcy and Hamilton Smith for pipes of small diameter, but the results he obtained with $1\frac{1}{2}$-inch lead pipes substantially agreed with those of the authorities referred to. The diagram on the vertical scale shows the coefficients plotted to a natural scale and the horizontal scale shows fall per 1,000 feet plotted to a logarithmic scale. The logarithmic scale is used so as to spread out the diagram with the flatter inclinations and contract it for the steeper ones, so as to enable a comparison between the coefficients for flat and steep inclinations to be more easily made.

It will be seen at once that all the recorded experiments show that C increases with s more rapidly with small pipes and less rapidly with large ones, also, the greater the inclination the less the increase in the coefficient.

At the left hand side of the diagram are plotted the coefficients given by Darcy's formula for the different diameters of pipes. In this formula C is constant for any slope, and in this respect Darcy's formula is clearly deficient. In practice, however, the author has found it to give for clean cast iron pipes results which under the particular conditions, viz., velocities of about 3 feet per second with pipes 3 feet to 3 feet 6 inches diameter agreed very closely with observed results.

The author would specially call attention to the coefficients for the Rosemary pipe given on the authority of Messrs. Fteley and Stearns

which are higher than anything met with in any other tests. Messrs. Fteley and Stearns are experimenters whose work has been so accurate that it is difficult to feel justified in ignoring these particular results, which are possibly due to abnormal smoothness in the surface of the pipes experimented with. The author's own experience has, however, shown him nothing to justify the suggestion that these tests are to be relied upon, and he considers it necessary in practice to adopt more conservative figures.

The thick curved lines in the diagram (see Plate II) are drawn to indicate what in his opinion would be proper coefficients for pipes with the diameters and slopes indicated. Intermediate values could of course easily be found by inspection.

What has been said so far relates to clean pipes which are the only pipes for which a fairly exact coefficient can be given.

Uncoated iron pipes very soon become covered with tubercules and then C rapidly diminishes. If well coated with bituminous solution the period before tuberculation sets up is greatly increased, but so far the author has never seen any pipes which did not show appreciable signs of tuberculation in 10 years. Efforts are being made to improve the bituminous coating of pipes, and it is possible that the period which will elapse before tuberculation takes place may be very greatly increased, possibly even tuberculation may be prevented altogether. Experience has shown that after the thickness of the tuberculation has increased to about 1 inch it increases no further for a very long time. In the case of the 44-inch main from Rivington to Prescot the discharge has remained practically constant for the last 10 years. In this case, after allowing for the diminution in the diameter of the pipe, C becomes 70·9 when s = ·00106. It is to be noted that this coefficient is arrived at after allowing for the diminution of the area due to the incrustation. If the coefficient is calculated on the original area of the 44-inch pipe it becomes 63·3.

The thin curved lines in the diagram (see Plate II) indicate what might be regarded as reasonable coefficients to be used after allowing for the diminution of diameter owing to incrustation 1 inch thick all round the pipe, and from these might be calculated with fair accuracy the minumum to which the discharge of any pipe is likely to be reduced as the result of tuberculation. In proportion to the amount of tuberculation C might have any intermediate value.

In a paper entitled "Notes on the Distribution of Water Supplies," read before the Society in 1894, the author gave diagrams showing the discharge through pipes of various diameters from 3 inches to 48

inches, with varying values of s, and for the actual practical work of designing aqueducts, such diagrams worked out from coefficients obtained as explained in the present paper are very convenient.

Even more remarkable than tuberculation in its effects in increasing the resistance to flow in a pipe, is a deposit of a dark brown slimy appearance not uncommonly found in pipes where the water from a peaty catchment area flows into pipes without having been filtered. The removal of a coating of this deposit about $\frac{1}{4}$-inch to $\frac{3}{4}$-inch thick increased C in the case of a section of the Vyrnwy aqueduct from 85 to 112. To all appearances the surface of this deposit was as smooth as the bituminous coated surface of the pipe. To account for the apparent anomaly Mr. Deacon ("Proceedings Institution Civil Engineers," Vol. CLVI. 40) explained that in the bottom of the pipe along with the slime were a quantity of small pellicles in appearance like coffee grounds. These pellicles on the uphill portions of the pipeline were continually being rolled up hill and falling back again, and acted as very efficient brake. In the length of main referred to there were 26 hills with a total vertical rise of 2,300 feet.

It has been suggested that the discharge from pipes is appreciably affected by the temperature of the water flowing through them. There appears to be no doubt that with pipes of small diameters there is an increase in the delivery with increased temperature. Professor Unwin found this to be the case with orifices, and Messrs. Saph and Schoder, whose work has already been alluded to, found that with small pipes the discharge does considerably increase with increase of temperature. This is nothing, however, to indicate that this effect extends to large pipes. The author has had no opportunity of making exact tests on the point, but he has been enabled to satisfy himself that if there is any effect at all it is very trifling, certainly for pipes over 36 inches in diameter less than 1 per cent. with ranges of temperature met with in England.

CHANNELS.

It is more difficult to obtain accurate tests in the case of channels than in the case of pipes. As a rule the inclinations are flatter, and owing to the channel having a free surface more difficult to measure accurately. Again, it is more difficult to obtain exactly the sectional area of stream, and lastly, there is a greater variety in the condition of the surface than in the case of pipes.

The diagram B (see Plate II) is for channels similar to the diagram A for pipes. The results of the chief tests which have been made

are plotted in black dotted lines, results of actual experiments being shown by dots.

Darcy's coefficients for five different classes of surface are plotted at the left hand of the diagram.

Kutter's coefficients for rivers and canals in moderate order $\triangle_9$ are plotted in thick curved lines.

RIVERS.

The determination of the flow down pipes and conduits or open-water courses is to the Engineer much more important than in the case of rivers. In these cases he is required from his formulæ to decide upon the properties of his pipes, tunnels and conduits, and any error might have serious consequences. In the case of rivers Nature has provided for the drainage of the country more or less perfectly, and the quantities discharged are wanted chiefly to enable the Engineer to ascertain the quantity flowing off drainage areas, or for the purpose of deciding upon regulating works.

The difficulties in determining accurately from the slope and sectional area of a river its discharge arises from the difficulty in determining all three of the necessary elements. In large deep comparatively slow running rivers the accurate determination of s is exceedingly difficult, and after all possible care has been taken it is probable that the results may vary very appreciably from the truth. The determination of the sectional area also presents difficulties, as unless sections are taken very close together it is difficult to make sure that the area determined really accurately represents the cross section. This, however, is the element which can be most accurately determined. The third difficulty is met with in the determination of the coefficient of roughness of the surface. Here the presence or absence of weeds makes an enormous difference in the discharge, and it is somewhat difficult, even when weeds are absent, to decide upon a proper coefficient. With care, however, fairly good results may be obtained, and it is probably possible to determine for moderate sized rivers the discharge from these data to within about 20 per cent., which is a sufficiently close approximation for many ordinary purposes of calculation.

In the case, however, of the necessity arising for a continuous accurate return of the discharge down a river, the only satisfactory method is that of adopting a cross section to work to, and the determination of the velocity past this section either by current meter or pole or other floats, a series of observations being made at various

levels of the river, a discharge curve can be plotted for the various levels of the river and such a discharge curve gives from day to day the discharge down the river and enables an annual return of the discharge to be made. It is possible in this way with current meters to arrive at within 2 to 3 per cent. of the truth in rivers of moderate size. The results of float observations are more uncertain, but even in this case the error should not greatly exceed 5 per cent.

In concluding his paper the author feels that he has only very imperfectly dealt with a very wide subject, and that possibly it might have been better had he confined his remarks to a narrower field, but he trusts that the members may, notwithstanding, find what he has written stimulate discussion and be of some use for purposes of reference. He would like to reiterate what he has said as to the need for further experiments. There is unfortunately in many minds an idea that to experiment is to waste money, and it is true that it is easily possible to indulge in more experimenting than can be justified. When, however, one considers the large sums of money expended in hydraulic works in various parts of the world, the expenditure of reasonable sums on tests which enable these to be designed with absolute accuracy seems a very proper application of capital. To the French Government which authorised and paid for the experiments of Darcy and Bazin, very largely belongs the credit for what progress hydraulic science has actually made. The Indian Government, in authorising the experiments of Major Cunningham at Rhoorkee, has likewise done its share, but the author is not aware that the British Government has done anything, and judging by experience, it is probable that further progress will be left to private or local effort, although the advancement of practical science by the use of Imperial funds seems a very proper field for their application.

APPENDIX I.

TESTS WITH $1\frac{1}{2}$-INCH LEAD PIPE (NEW).

L = 73 feet.

D = ·125.

H is the difference in feet between reading of level of water in piezometer after uniform flow had been established and surface of water in tank into which pipe delivered.

H	Discharge in Gallons per hour	Mean Velocity in feet per second	s	C
6·26	1514	5·479	·0857	106·4
4·843	1339	4·862	·0663	105·2
2·93	978	3·351	·040	100·5
1·858	740	2·687	·0254	95·5
·193	210	·762	·0026	84·1
·066	103·8	·376	·0009	71·1
·034	70·9	·257	·00046	67·4

275·4 gallons per hour = 1 foot per second. See velocity.

APPENDIX II.

VALUE OF C IN DARCY'S FORMULA FOR DISCHARGE OF PIPES (CLEAN CAST-IRON).

Diameter Inches	C	Diameter Inches	C
48	112·3	12	109·0
42	112·1	9	107·7
36	111·9	6	104·9
30	111·6	4	101·6
24	111·1	3	98·4
18	110·8	$1\frac{1}{2}$	88·0
15	109·9	—	—

APPENDIX III.

Table of Values of C calculated by Ganguillet and Kutter's formula for channels and rivers.

Value of r in feet	Value of s.						
	·00001	·00002	·0001	·0002	·001	·002	·01
	1 in 100,000	1 in 50,000	1 in 10,000	1 in 5,000	1 in 1,000	1 in 500	1 in 100
$\triangle_1$ SURFACE OF PLASTER IN PURE CEMENT. $n = \cdot 010$.							
·25	—	—	105	114	119	120	121
·50	—	—	127	133	139	140	140
1	—	—	150	152	156	157	157
5	—	—	192	188	188	188	188
10	—	—	205	202	198	198	197
$\triangle_6$ SURFACE OF RUBBLE. $n = \cdot 017$.							
·25	—	—	52	56	60	61	61
·50	—	—	66	70	73	74	74
1	—	—	81	83	86	86	86
5	—	—	115	114	113	—	—
10	—	—	128	125	—	—	—
$\triangle_9$ RIVERS AND CANALS IN MODERATE ORDER.							
·25	19	20	25	27	29	29	29
·50	26	28	33	35	37	37	37
1	36	37	42	44	45	45	45
5	74	70	67	66	66	—	—
10	95	89	77	76	74	—	—
75	183	150	105	98	—	—	—

DISCUSSION.

Mr. Cooper

Mr. F. E. Cooper said—I will not hesitate to open the discussion as I have quite a fellow feeling for the author, the subject being one in which I am very much interested. I have lately got rather rusty on the question of hydraulic formulæ, and the author's very able treatment of the question has been extremely informing. The author's side of the question is principally devoted to the bringing of a supply of fresh water into the town, and for some years mine was the carrying of the dirty water out again. But both of us have had to use formulæ for calculating discharge; he, of the water mains, and myself of the sewers.

I think anyone can gather from the paper that the author, like most of those who deal with hydraulics, has a pet formula of his own, and I may say that I am very much in the same position. For a great many years I pinned my faith on a formula for calculating the discharge of sewers, but ever since Mr. Santo Crimp conducted those experiments of his at Barking and Crossness, I took over the formula which Mr. Santo Crimp and Mr. Bruges introduced and which the author mentions on page 123 of his paper. Of course it is one of those which come under the head of class (*c*) which the author speaks of and which departs from the well-established formula of dealing with the $\sqrt{rs}$. I must admit that I was rather surprised that the author dismisses this formula in two or three lines, as the experiments were conducted on very large sewers indeed, but perhaps these will not appeal to him as much as they do to me. I think the formula of Mr. Santo Crimp is going to stand, because he had most exceptional opportunities of conducting experiments on a very large scale. That I think somewhat explains why most of the earlier experimenters failed with their formulæ. They nearly all conducted experiments with small pipes and were led to suppose that what was true of a small pipe was equally true of a large pipe. Of course the whole thing turns upon the value of C, and any beginner taking up the use of any of these formulæ would not know the value of C. In the author's case he knows perfectly well the value of C and can adapt the formulæ to the proper circumstances of the case.

On page 126 the author speaks of the deposit of a dark brown slimy appearance. Such a coating is probably not confined to water mains, as I remember in one particular sewer, of a gradient of

about 1 in 150, lined with blue bricks, these bricks, while quite clear of deposit, were so slippery that with a pair of rubber boats on, you could slide ten or a dozen yards with a slight push, and not with a great depth of water either. Mr. Cooper

I would first like to ask the author a question as to notch gauging. My own recollection of going on the Vyrnwy works before the dam was started was seeing a weir-board fixed on the Vyrnwy River for the purpose of gauging; is this system still in force?

At the bottom of page 129, the author says, "It is possible in this "way with current meters to arrive at within 2 or 3 per cent. of "the truth in rivers of moderate size." I should like to ask the author how he knows that he is able to get within 2 or 3 per cent. If he knows this, it seems to me that there is no need to make experiments. Perhaps he will let us know how that is arrived at.

I think it would be very instructive if the author would go to the trouble of preparing a diagram showing the relative results obtained by the formulæ he has dealt with. We have here the various formulæ given to us, but it would be very interesting indeed if a chart were given showing what the results of the different calculations are. There are such relative charts given in Santo Crimp's hydraulic tables—he gives Kutter's formulæ and half-a-dozen others, and it is most instructive to see the difference one gets by the adoption of the different formulæ.

Mr. G. R. Bayley said—There is just one question which I should be glad if the author could answer for us. Some time ago we used to meet with formulæ published by Mr. Box as the result of his experiments, and I should like to know whether the author has studied these in the light of his experience and how far they agree with the results of his observations. Mr. Bayley

Mr. Somers H. Ellis said—I should like to express my indebtedness to the author for his paper, which is extremely valuable to those who, like myself, have not an intimate knowledge of this subject, in giving, as it were, a clue to the formulæ which one finds in such a book as Molesworth. Mr. Ellis

I had occasion, some years ago, to calculate the discharge of a large Indian river, and found it then very difficult to determine what formula and what coefficient to use. One finds in Molesworth half-a-dozen formulæ, each giving a result to four places of decimals, but with wide differences between them; and it is puzzling to know which to select.

The author says that it is more difficult to calculate the discharge

Mr. Ellis of rivers than of channels or pipes; and especially is this the case in India, where the width of the river may vary from $\frac{1}{4}$ mile to 2 miles, and the discharge of course increase enormously in flood-time. The nature of the bottom, too, may vary from boulders to sand. One has, too, to calculate the discharge of floods over cultivated ground, so as to provide bridges capable of taking away the utmost discharge.

I remember one case in which the line of a railway in course of construction ran parallel to the Grand Trunk Road. In one place there were a large number of flood-openings in the latter—I think something like 40 of 30 feet span. By all the calculations we could make, and by records of floods, there appeared to be no necessity for such a large number of openings, and it was proposed to reduce the number in the railway embankment by about one-half. Fortunately, before the line was constructed a higher flood than any of which there was record came and showed the necessity for the utmost capacity provided by the road.

If one has the drainage area and the possible rainfall, it should be possible to calculate what the discharge would be in such a case as this; and the paper is most helpful in showing the basis from which the various formulæ are worked out.

Mr. Flinn Mr. Hugo Flinn said—The moral of the author's paper seems somewhat opposed to that of Mr. Grundy's a month ago. Both agree that for practical engineering calculations formulæ based on first principles are essential—they differ in that Mr. Grundy believes that for things subjected to stresses so complex as those in marine engine parts, a formula based entirely on theoretical considerations is quite adequate without constants; the author believes that for the calculation of something seemingly much more straightforward—the sizes of water pipes for required flow with given head—the constant is the all important thing. The other contention of his paper is that not theory, but experience will determine what that constant shall be.

The truth seems to be that while first principles are good, experience in their use in practice is essential, and not either, but both combined with commonsense will give sound engineering results.

Mr. Miller Mr. Thomas L. Miller said—It is so long since I had to do with hydraulic work that I have felt a considerable amount of diffidence in taking part in the discussion; Mr. Flinn's remarks, however, have brought me to my feet.

Mr. Flinn has just stated that from the author's paper, and from a previous paper read before the Society, it appears that in

dealing with formulæ one requires to have a certain amount of commonsense and then the formula. I would rather reverse the order of things and say that having a formula a certain amount of commonsense is required in order to apply it to the particular work one has in view. Mr. Miller

Mr. Flinn has also referred to a previous paper bearing on formulæ containing constants, wherein such formulæ is stated to be unscientific. Now I think the remarks on the paper in question should not be taken too seriously, for a very large number of formulæ, based on the result of experiments, necessarily contain constants.

The method of obtaining formulæ from experiments, as is well-known to most of the members present, is roughly as follows :—

A series of experiments are made and the results plotted on squared paper. A curve is then drawn which gives the average results of the experiments and a formula is found which fits the curve. The curve and consequently the formula represents the laws governing the particular matter which has been the subject of the investigation. This being the case such formulæ can in no sense be termed "rule of thumb," as they have as truly a scientific basis as any formulæ based on mathematical analysis.

I merely mention this, as I fear the result of the paper to which Mr. Flinn has referred may have the effect of unsettling the ideas of some of the younger members of the Society.

I stated that, in addition to the formulæ, a certain amount of commonsense was required in the use of same, and this is very well illustrated by some of the formulæ given by the author in his paper and Mr. Cooper's remarks. The author in his paper has referred to certain experiments which he carried out on some $1\frac{1}{2}$-inch pipes, and Mr. Cooper has also referred to some formulæ based on some experiments carried out by Mr. Santo Crimp on a 9-foot sewer.

Now it will be quite evident that for anyone to apply the author's formulæ for $1\frac{1}{2}$-inch pipes to a 9-foot sewer would be absurd, and in like manner Mr. Santo Crimp's formula applied to $1\frac{1}{2}$-inch pipes would give equally absurd results.

Commonsense would tell us that in using a formula for the flow of water, one should, if possible, obtain some particulars of the experiments upon which the formula was based, and only apply the formula within the limits of the experiments, as otherwise there is grave danger of the results obtained being erroneous.

Of course if no series of experiments cover the particular conditions

Mr. Miller with which one has to deal, one would take the particular experiments which most nearly met the case.

At one time I had a considerable amount of work in connection with waterworks pumping engines, and for this particular class of work used a formula first given, I believe, by Mr. James Simpson, a Past President of the Institution of Civil Engineers, who carried out a large number of experiments on the flow of water in pipes, and deduced the following formula :—

$$V = 50 \sqrt{\frac{D \times h}{L + 50D}};$$

where V = the velocity of the water in the pipes in feet per second.
D = the diameter of the pipe in feet.
h = the friction head in feet.
L = the length of the pipe in feet.

Mr. Simpson claimed that this formula agreed very closely with the results of his experiments.

In conclusion, I would only like to say that I think the Society is very much indebted to the author for having brought this interesting paper before us, as I am sure his remarks on the various formulæ will be very valuable to those who have to deal with hydraulic problems.

Mr. Priest The President, Mr. Frank E. Priest, said—Mr. Flinn's remarks concerning the need of commonsense are most apt. In the use of hydraulic formulæ commonsense is required, not only in selecting the formulæ but in using them.

The chief lesson of the paper seems to be that the value of C should not be found by an equation however cumbersome it may be. Its value can only be ascertained with accuracy by experiment, and where this cannot be done it must be estimated from other experiments where the conditions were as nearly similar to those of the case in question as can be found. For this purpose a collection of experiments made with care is of the greatest value and commonsense in their use is equally necessary.

I am waiting with considerable interest to hear what the author says in answer to the question as to how he checked the correctness of his calculations of the flow of large rivers. Of course it is difficult to know whether the lines you are working on are the correct lines when you are dealing with such a matter as that, but there is this consolation, that if you do not know all the conditions necessary for your purpose the chances are that nobody else does, and further, in the case of very large rivers, perfect accuracy is not of the same

importance as it would be in the designing of (say) an aqueduct. Sometimes weirs are in existence in large rivers, and when they are of suitable form they afford a second means of measurement of flow which serves as a check for the other method. Mr. Priest

Mr. DUNCANSON, in reply, said—I beg to thank you for your vote of thanks and would express the hope that the paper may be useful for reference. Mr. Duncanson

Now in regard to the criticisms ; first, I would like to say I heard a good many years ago a distinguished engineer say, in speaking of formulæ, that an engineer should control his calculations and not let his calculations control him, which is another way of expressing what has been said to-night about the need for commonsense in using formulæ.

With regard to Mr. Cooper's remarks, Mr. Santo Crimp, in the paper referred to, states that his formula is founded on Darcy's and Borzin's experiments, but no doubt it would be tested by results obtained from his own practice, but I do not know of any reference to this. Mr. Cooper also referred to notch gauges ; well, I have had a good deal to do with the use of notches and know that exceedingly accurate results may be obtained with them. A number of years ago I acted as assistant to Mr. Deacon in carrying out experiments on a notch gauge 8 feet long with end contraction suppressed. The water was discharged into a carefully calibrated gauging chamber, and tests were made on varying heads up to 2 feet 6 inches deep, and the results obtained confirmed each other to within about $\frac{1}{4}$ per cent. When a continuous record is required it is obtained by means of an automatic recorder. These latter want some looking after, and it is difficult to get them to record as accurately as the experiments on which their calibration is based.

Then Mr. Cooper asks, how one knows it is possible to get within 2 or 3 per cent. of the truth in the discharge of rivers of moderate size by means of current meters.

The particular river I had in view was the Vyrnwy, and comparing the results of the quantity discharged as ascertained by means of current meters and automatic recorders with the rainfall on the drainage area, the difference between the observed discharge and the observed quantity of rainfall on the drainage area were such as were expected, and such that the error in the discharge ascertained from the current meters could not have exceeded 2 or 3 per cent., and if in a river of this size you can get within 3 per cent., there is no reason why you should not get as accurate results if you work on a larger river.

Mr. Duncanson

Mr. Bayley referred to Mr. Box's formula. I have used Box but omitted to refer to him in the paper, although he has done useful work. His formulæ are of the class with a constant coefficient.

Mr. Ellis referred to the formulæ in Molesworth and the way to apply them. What I have tried to do in the paper is to get at the heart of the principles on which the various formulæ are based.

I do not know how far I have succeeded, but what I wanted to do was to show the comparison between coefficients used in the different formulæ and those obtained from actual experiment.

With regard to the case of the $1\frac{1}{2}$-inch pipe of which I give tests and which someone referred to a little sarcastically, I purposely tested a small pipe to ascertain the effect of variation in S on the coefficient in such a pipe, the effect of S being more pronounced than in a smaller pipe.

Mr. Miller referred to Simpson's formula

$$V = 50 \sqrt{\frac{D \times h}{L + 50D}}.$$

Well, that is really a very slight modification of the expression $v = 100 \sqrt{r\,s}$. The expression $50D$ has considerable effect on the calculation in the case of short pipes and little in the case of long ones, and is intended to allow for the loss of head necessary to produce neutral velocity. This formula will be quite accurate in particular cases.

In the coefficients I have given I have not considered the question of the head necessary to produce natural velocity, and as I mention I have assumed uniform flow to be set up prior to the formulæ given being applied.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

EIGHTH MEETING—22ND FEBRUARY, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

SUNDRY NOTES ON DOCK CONSTRUCTION.

BY FIELDEN SUTCLIFFE.

WHEN the author agreed to read a paper before this Society, he had no very clear idea what form it would take, but to allow of some title being used it was called "Sundry Practical Notes on Dock Construction."

He has since, however, thought it well that besides dealing with certain practical points with which he is conversant, it would not be uninteresting to the members of the Society, particularly, perhaps, to some of the younger members, that some slight sketch of the history of docks should be given, and he has amended the title accordingly.

For the purpose of this paper docks may be defined to be enclosures for the reception of ships, and to be of two kinds, wet and dry.

A wet dock admits of ships being kept afloat at all states of tide, and affords facilities to discharge and load them, to fit them out, and to repair their upper works and machinery.

A wet dock is generally surrounded by quays on which are provided suitable accommodation for the reception and delivery of merchandise for and from the ships, and for its storage.

At its entrance, as a rule, there are gates to retain a sufficiency of water within the dock, but in situations where the range of tide is small, gates are not required.

A dry or graving dock provides for every part of a ship's hull being examined and repaired, and may be used as a shipbuilding site also. If a graving dock be entered from a wet dock having ebb gates, one pair of gates opening outwards, or a single acting caisson only is necessary; but if it be entered from a tide way, then two pairs of gates in reverse positions are needed for the safe blocking of ships, unless their equivalent, a double-acting caisson be employed.

A ship making use of a graving dock is floated into it and is made to settle down by running off or pumping out the water, as the case may be, until its keel bears upon a range of adjustable and removable blocks which are set on the dock bottom, and when in an upright position, the ship is shored to the side walls or altar courses of the dock, the water is then run off or pumped out, and the dock is kept dry by pumping until the ship's repairs are completed, and then water is re-admitted through sluices and the ship is floated out.

Such, at least, is the modern conception of a dry or graving dock and of its use. The dry dock of the early days of dock construction was simply an artificially protected beach, or a shallow open basin, affording a measure of safety to ships while they were being either discharged and loaded or repaired, a ship entered the dry dock at high water time, grounded and dried on the falling tide, and for cleaning or repairing its bottom at low water time had to be careened.

The first Act of Parliament authorising dock construction in this Kingdom was passed in the year 1709, and in virtue of that Act the Corporation of Liverpool constructed a wet dock at the mouth of the Pool, a shallow creek bounding the old town from South West around to North East.

That dock, afterwards known as the "Old Dock," had a water area of three acres, 1890 square yards; its sill was at a level of 4·67 feet below ordnance datum at Liverpool.

The level of the "Old Dock Sill" is the datum for the port.

Prior to the opening of the "Old Dock" for the reception of ships, the trade of the port was sorely handicapped by reason of there being no place where vessels could lie in safety. Ships on entering the harbour to deliver or take in cargo rode at anchor in the stream, or lay aground on the open beach in front of the town to discharge or to load, and while so placed they were frequently battered and damaged or wrecked by the force of on-shore gales and accompanying heavy seas, to the great loss of merchants and shipowners and hindrance to trade, and the conveyance of merchandise to and from the ships

lying on the beach, and in the river by carts and lighters was inconvenient, tedious and costly.

When the dock was opened, however, a complete change was wrought, ships on entering it could lie in safety and be discharged, loaded and re-fitted conveniently, cheaply and expeditiously ; the time required for a ship to remain in port was thereby materially shortened, and the ship's value as a freight earning machine was enhanced.

The dock proved to be a boon to all concerned, and its acquisition greatly improved the position of Liverpool as a seaport ; trade expanded rapidly and ships frequenting the port increased, both in number and in average tonnage, and ere long the capacity of the dock was found to be insufficient to meet the requirements of trade.

Under those circumstances the Corporation determined on extending the dock accommodation, and under an Act of the year 1737, there were constructed and opened to shipping in 1753 the Salthouse Dock, together with a pier, which had been run out in a Westerly direction to about low water mark from the North side of the Old Dock, so as to form an open basin for the use of coasting vessels, and to act as a breakwater covering from seaward exposure, both the Old Dock entrance and that of the Salthouse Dock which lay to the Southward and Westward of the Old Dock.

That extension of dock accommodation soon proved to be inadequate to cope with the requirements of an expanded and rapidly growing trade, and under the powers of later Acts other docks were constructed, of which the George's Dock with George's Basin were opened in 1771, followed by the King's Dock and Queen's Basin in 1788, and by the Queen's Dock in 1798.

Thus, before the end of the 18th Century, there were at Liverpool five wet docks and three open basins, the former totalling 27 acres water space and two miles lineal of quay space, and the latter having a total area of 10 acres water space and about three-quarters of a mile of lineal quayage.

There were also provided graving docks for ship repairing and ship building.

At that time the only other commercial wet docks in the Kingdom were a dock at Leith made in the year 1720, and the Old Dock at Hull, constructed under an Act of 1774, if we except the Greenland Dock and a dock at Blackwall, each of which was constructed by a private ship builder, and leaving them out of the count, London's first docks may be taken to be the West India Docks which were commenced in 1800, and opened two years later.

The first docks at Bristol were begun in 1805 and opened in 1809.

At the beginning of the 18th Century the only means of inland carriage from the port of Liverpool, except that the Mersey had been made navigable to Warrington, was by road, and the roads were wretchedly bad, consequently as compared with London, Bristol or Hull, with their far reaching natural waterways, Liverpool was at a disadvantage.

The Mersey and Irwell navigation carried out under an Act of 1721, afforded a measure of relief in that it provided water carriage from Manchester to the navigable waters of the Mersey. The river Douglas navigation from Wigan to the river Ribble, although a circuitous route, was of some assistance in the transport of coals to Liverpool, and the making navigable of the river Weaver under Act 1720, from Frodsham to Winsford Bridge, and extending that navigation under an Act of 1734, brought the salt mines and manufactories of Cheshire into easy communication with Liverpool.

No further advance of any importance in the matter of inland carriage was made until the Bridgewater Canal, under an Act of 1759, was commenced, that work connecting Manchester with the Mersey at Runcorn was completed in 1776, and in the following year the Trent and Mersey Canal was opened. The Leeds and Liverpool Canal was commenced in 1769, and a section of it from Wigan to Liverpool was opened in 1774, and the Ellesmere Canal was opened to the Mersey in 1795, these trunk lines of canal, together with a network of minor canals and connections with navigable rivers which were made before the end of the 18th Century, served admirably the purpose of distributing and collecting merchandise over the wide expanse of country which they traversed, and made Liverpool the Western port for the Midland and Northern Counties of England where manufacturing industries were numerous and thriving.

These improved means of inland carriage, together with the great lead of other ports in the Kingdom, taken by Liverpool in providing dock accommodation for ships, made its port a centre of commerce having facilities for trade second to none, with the result that the increase of shipping kept pace with that of the dock space.

Trade with India and China having been freed of the East India Company's monopolies in the years 1814 and 1833, respectively, further opportunities of extending commerce were given, of which Liverpool took full advantage, and the opening of the Liverpool and Manchester Railway in 1830, closely followed by numerous other lines

of railway throughout the country, greatly increased the means of internal communication, reduced the cost of inland carriage, and improved trade generally.

The first Steamboat on the Mersey was one plying between Liverpool and Runcorn in the year 1815, and in 1819 there was steamboat communication between Liverpool and Glasgow, Dublin, and Belfast. In 1838 the City of Dublin Steam-Packet Company's paddle wheeled steamer "Royal William" left Liverpool for New York; in 1840 the first Cunard liner "Britannia" sailed for Halifax; in 1845 the celebrated "Great Britain" was put on the Liverpool and New York trade, and in the same year a line of screw steamers was started in the Levant trade.

The number of steamers sailing out of Liverpool increased rapidly, and in the year 1837 two docks, the Clarence and Trafalgar, were appropriated exclusively to the use of steamers.

The Clarence Half-tide Dock entrance (50 feet in width) was then the widest entrance in the port, and it became necessary to construct docks having wider entrances in order to provide for large paddle steamers, then either in course of construction or about to be built.

Consequently there were constructed and opened in 1840 the Coburg Dock, in 1851 the Wellington Half-tide Dock, Wellington and Sandon Docks, all of which had entrances 70 feet in width, in 1852 the Huskisson Dock with an entrance lock 395 feet in length and 80 feet in width, which had been specially designed to meet the requirements of the Collins Line of American paddle steamers, and in 1858 the Canada Dock with an entrance lock of 498 feet in length and 100 feet in width.

The sills of those six docks were at depths below the Old Dock Sill as follows, viz.:—Coburg, 5 feet 7 inches; Wellington Half-tide, Wellington and Huskisson, each 6 feet 6 inches; Sandon, 6 feet; and Canada, 7 feet 9 inches; and they were the deepest docks in the port.

On 1st January, 1858, when the Liverpool Dock Estate and the Birkenhead Dock Estate, which had been purchased by the Corporation of Liverpool from the trustees of the Birkenhead Docks, were vested in the Mersey Docks and Harbour Board, there were at Liverpool 31 docks having a total water area of 188 acres, and quay space nearly 14 miles in length, and at Birkenhead there were two docks with a combined water area of 7 acres.

The area of water space at Liverpool docks is now 369 acres, and

the length of their quays is over 25 miles; and the Birkenhead docks have now an area of 160 acres water space and 9 miles in length of quays.

At the time of the opening of the Canada Dock ample provision had been made in the matter of width of entrances, but the largest class of vessels frequenting the port were unable to enter or to leave the docks during low neap tides owing to an insufficient depth of water, and much inconvenience was caused by such vessels having to wait for a suitable tide or to lighten in the river or to complete loading there.

In the year 1866 the Alfred Dock at Birkenhead, with sills 12 feet below the Old Dock Sill and its main entrance of a width of 100 feet, was opened, and in 1881 a like depth of water was provided at Liverpool at the Herculaneum Dock, and at the Langton-Alexandra system of docks. Meanwhile the great ocean-going paddle steamers had been superseded by screw steamers, and for a time the tendency in shipbuilding was to increase length and depth without a corresponding increase of breadth of beam. The Langton river entrances were given a width of 65 feet, and the passages between Langton and Alexandra Docks were made 60 feet in width.

The increase of 4 feet 3 inches in depth from Canada to Langton entrances was at the time looked on as a great advance, but ships went on increasing in size, each new arrival being larger than the ship which preceded it, and in a few years time scant water again became a serious difficulty, and more so at the Mersey Bar than at the docks, and there could, therefore, be comparatively little advantage derived from a further deepening of the docks unless the bar also were deepened; a keen competition in the Atlantic trade was ever introducing a larger and faster vessel to make "record" passages, and the time gained in speed of travel was frequently lost by the vessel having to lie off the bar until a rising tide gave a sufficiency of water for the bar to be crossed.

And there was a further inconvenience to such vessels that the time of their sailing from Liverpool could not be made constant so long as the bar could not be crossed at any state of tide.

In 1883 the present Harrington Dock was opened, and the Toxteth Dock was opened in 1888, both docks having a 12 feet depth below datum at their passages.

In 1890 it was determined to test, experimentally, the feasibility of deepening the bar, and to that end two steam hopper barges, each of 500 tons carrying capacity, were fitted with suitable pumps for raising

sand, and they were set to work on the bar to remove sand therefrom to a dumping site, some miles away, in the deep.

The success of those experimental dredgers was so marked and encouraging that in 1892 a 3,000-ton vessel with improved appliances was ordered, and that vessel, named the "Brancker," was got to work in the following year, when it was found that the two smaller vessels had opened a channel through the bar 1,000 feet in width, and having a depth of 16 feet at its sides, and 18 feet on its centre line, as against a depth of 11 feet prior to the commencement of dredging operations. The depths given are below low water of equinoctial spring tides.

In August, 1895, the minimum depths in the cut varied from 20 feet at its sides to 24 feet at centre line, and the width of cut was increased to 1,500 feet. In the same year another vessel similar to the "Brancker" but capable of dredging to a greater depth was got to work, and the two smaller vessels were withdrawn.

The bar was lowered to 27 feet below low water of equinoctial spring tides, and is being maintained at that depth by one dredger.

Since 1900, when the deepening of the bar was commenced, vast improvements have been carried out at the docks, the group of docks from Canada Dock to Wellington Half-tide Dock has been to a great extent remodelled.

There have been constructed new river entrances 100 feet, 80 feet, and 40 feet in width, respectively, the two former having a depth of 20 feet 6 inches, and the latter, a lock, a depth of 16 feet below the Old Dock Sill.

Those entrances open into a new dock named the Sandon Half-tide Dock, which covers the site of the Sandon Basin, and of the Wellington Half-tide Dock.

The Sandon Dock has been altered and deepened, its passage 90 feet in width, and 20 feet 6 inches in depth below datum, communicates with the Sandon Half-tide Dock, and there is a like communication between the latter and the Huskisson Dock which has been deepened and to which a third branch dock has been added.

The Canada Dock has been enlarged and deepened, a graving dock and two branch docks have been constructed at its eastern side, it communicates with the Huskisson Dock by a new passage 90 feet in width, and of a depth of 14 feet below the Old Dock Sill, and its entrance lock has been lengthened from 498 feet to 600 feet, and deepened from 7 feet 9 inches to 14 feet below the Old Dock Sill.

The shallowness of the group of docks from Canning to Brunswick inclusive has, in a measure, been remedied by impounding the water

over low neap tides, and by making the Union Dock, which has a 12 feet sill, their locking entrance and supplying any water that may be lost by pumping from the river.

The Birkenhead Docks, also, are worked on the impounding system, and the Alfred Lock is deepened to 18 feet below the Old Dock Sill.

The Brunswick Dock is being deepened and has new river entrances of 100 feet and 80 feet in width respectively, with a common depth of 19 feet 6 inches below the Old Dock Sill.

The effective depth of an entrance, as compared with the nominal depth (which is that of its centre line), may depend on the form of the sill and on the midship section of vessels using the entrance.

In the early examples of dock construction the cross section of a sill was that of an inverted arch, the intrados of which was usually a large segment of a circle, giving considerable rise to the sill.

A sill of that form bore a great portion of the weight of the side walls of entrance and was thus made strong to resist pressure from below.

And so long as the width of entrance was not much in excess of that of vessels using it and their midship section had a rise of floor and round of bilge sufficient to clear the sill its rise caused no inconvenience.

But the introduction of paddle steamers necessitated the making of much wider dock entrances, and although the rise of sill did not affect those vessels it served to reduce very materially the effective depth of entrance for large sailing ships and screw steamers.

That inconvenience was increased as the midship section of vessels became fuller, and for the typical ship of to-day, with a midship section almost rectangular, any rise of sill amounts to a reduction of the depth of entrance, hence the flat sill of recent practice.

A dock sill, under certain conditions, may be open to water pressure acting vertically upwards at its foundation.

A foundation pervious to water, and open to the influence of water at a higher level, is a condition of things under which such pressure may be present.

And the maximum intensity of that pressure would obtain when the chamber of entrance was pumped dry and the outer water was at its highest level. The pressure in tons per square foot may be taken at $\frac{H}{35}$ where H represents the head in feet.

And unless that pressure either be met by a sill sufficiently strong

to withstand it or be not allowed to accumulate, failure of the sill is inevitable.

If the foundation be of porous rock, like the local red sandstone, through which water under pressure may ooze, unless that water be relieved by means of vents, it will exert the full pressure due to the head.

For such a case a remedy is easily provided, because the water percolates through rock, and therefore carries no solid matter with it, and its volume is a negligible quantity.

The drawing marked A shows an arrangement of vents or weep holes such as has been carried out at Liverpool in the case of all entrances founded on rock, since the flat sill was introduced.

Stated shortly, that arrangement consists of the planting of 4-inch diameter earthenware drain pipes, on end and socket down, on the foundation, laying a few small rubble stones about the foot of each pipe, and spacing them six feet apart, the one from the other, in both directions.

Then the laying of concrete of sill, &c., is proceeded with, and other pipes are planted on top of the bottom lengths, and so on until the required level is reached, when a wooden print is placed on the top of each pipe about which is moulded in concrete a seat for a cover. When the concrete is set the holes are extended about a foot into the rock with a jumper, cleaned out and covered with a flag or tile laid flush with the surface and without being cemented. Those covers serve to keep out silt and admit of the issuing of water from below.

In a situation where sand or gravel is the medium through which water under pressure reaches a sill foundation, assuming that means have been adopted, whereby communication with the outer water has been so far cut off, that only a moderate leakage can occur, the water bearing strata beneath the sill may with advantage be given a vent; but care should be taken to filter the water in its passage and to give to it such freedom of exit that the issuing velocity shall be low in order that solid matter shall not be discharged.

A kindred example of the need of draining foundations is that of a graving dock, where not only for the safety of the floor of dock, but also for the convenience and comfort of workmen and others who may be engaged there, it is required that there shall be thorough drainage. In this case vents discharging vertically upwards are inadmissible, except at the side channels, because it is important that the floor be kept dry.

At the Langton Graving Docks drains of 6-inch open jointed earthenware pipes were laid in grips cut in the rock on diagonal lines from the sides to the centre line, and surrounded with shingle, the pipes deliver into gulleys at the side channels.

The Canada Graving Dock, of which Figure 1, Plate V, is a cross section of the middle of the dock, is 925 feet in length and has an entrance 94 feet in width and 13 feet 3 inches in depth below the Old Dock Sill; the top of the keel blocks is at the same level, and they stand 4 feet above the crown of the floor, which is cambered and falls 6 inches from centre to side channels.

The twin culverts, one on each side of the line of keel blocks, extend from a rudder pit at the head of the dock to another rudder pit at the back of the sill at entrance, from which a cross culvert leads to the pump well.

The twin culverts increase in combined area gradually from 20 superficial feet at head of dock to 60 superficial feet at the lower end.

The cross drains are of 18-inch earthenware drain pipes, and they are spaced 25 feet apart.

The primary object of those culverts and cross drains is to lead off water to the pumps speedily after the crown of the floor of dock at its lower end begins to bare, the water then flows readily to the side channels, owing to the cross fall, and thence through gulleys to the 18-inch drains to the twin culverts, and so on, to the pumps.

They have also been made to serve as reliefs for water coming from springs and other sources which, if allowed to accumulate when the dock is dry, might bring about the destruction of the floor.

The 18-inch pipe drains are made capable of receiving water from the ground by having the lower half of the pipes embedded in shingle and their joints open to that extent (see Fig. 2, Plate V). The culverts also are made to admit water through holes, other than the cross drains, formed in their outer sides and in the bottom wherever there was an appearance of water in the ground, and about those holes at the sides, if above the rock, a quantity of rubble stone was packed to serve as a filter bed.

The ground behind the side walls of dock is thoroughly drained by means of earthenware pipes extending from the face of bottom altar course through the wall and up the back to near the surface of quay, the rising pipes are open jointed and rubble is packed about them.

The result of these precautions in the matter of ground drainage is a dock, dry in fact as well as in name, void of any weeping from side walls or floor, and thoroughly sound throughout. The central culverts

serve also as reservoirs from which circulating pumps connected with a vessel's refrigerators may draw water—eyes having been provided for that purpose.

Reverting to the deepening and lengthening of the Canada Lock.

That improvement involved the underpinning of the South Pier-head of Canada Basin, the deepening of its Southern half, the construction of a timber wharf having a base of concrete in which were embedded sluicing culverts of cast-iron pipes, the building of an outer sill to the Northward of the old one, the underpinning of the side walls of lock, and the removal of the old floor of chamber, excavating deeper down and laying a new floor with intermediate and inner sills for lock gates.

The lock was lengthened at the basin end, and the new outer sill-work had to be carried out in a tide way.

A piled dam backed with clay served to keep out the tide when it was below the Old Dock Sill level, and the work was done at low water of spring tides. Three large sized chain pumps, having casings 2 feet 6 inches by 6½ inches, were provided and fitted up in a piled well at the back of the new North-east pier head of the lock.

The pumps were driven by a semi-portable steam engine fixed on the quay, and a staging erected upon the well piles carried the outer end of the driving shaft and the pump reels.

The delivery lander was at a level of the Old Dock Sill, and at a lower level there was fixed a blow lander with a governing paddle by means of which, on the return of the tide, water was admitted to flush the drains and partially to fill the dam with water before the tide commenced to flow over it, in order to prevent damage being done by the falling water.

For tide work a chain pump is invaluable because it is a good rough and efficient appliance that is easily kept in order, and because it is direct in its action, and having no valves, it is a ready and effective means for the removal of silt, slurry or running sand, and further, because its real shaft may be placed well above high water level and its working parts can be overhauled between tides.

The efficiency of a chain pump may be taken to be from 35 per cent. to 60 per cent. of the power applied to the driving shaft, the lesser value obtains when the return buckets are driven through a great depth of water, and the greater when there is just sufficient cover of water on the mouthpiece to admit of a full charge being carried into the pump casing.

A chain pump, having a casing measuring 2 feet 6 inches by 6½ inches in cross section, and driven at a chain speed of 550 feet per minute, will discharge over 20 cubic yards of water per minute.

Two such pumps were erected to empty the Canada Lock and keep down the leakage while the deepening work was in hand, a well was sunk for them in the floor of lock chamber to a depth of 31 feet below the Old Dock Sill, and in order to avoid having to raise the water over the top of the wall, which was 28 feet above the Old Dock Sill or 59 feet above the bottom of well, arrangements were made whereby the pumps discharged into a culvert in the wall, which led out to the river.

That culvert was at a level of 5 feet above the Old Dock Sill, practically the mean level of the sea, and at that level a wooden floor was laid through which the cast iron pump casings were extended about a foot in height and upon that floor a wooden shaft, divided into three compartments by two vertical bulkheads, was erected to a height of 19 feet, the end compartments served to contain the water rising from the pump casings until there was a sufficient head to cause it to flow through openings (covered by self acting clacks) at the bottom of the bulkheads, into the central chamber, and thence by means of a box lander to the culvert in the wall, and through it to the river.

By that arrangement the water to be pumped required to be raised only sufficiently high to cause it to flow through the culvert when the tide was below that level and as much above the level of the tide when the tide was above the culvert level.

The working model exhibited shows a similar arrangement for a chain pump.

The new outer sill of Canada Lock was laid upon a bed of marl at a depth of 24 feet below the Old Dock Sill, and it was formed of concrete 10 feet in thickness with granite ashlars for the keel of a caisson to bear against and other granite ashlars to take the gate sill-wood fastenings.

While the sill was being constructed the old flood gates were closed, and between them and the inner ebb gates the lock chamber was pumped dry. On the floor of the chamber an excavation was in hand at a distance of about 30 yards from the excavation for the new outer sill, when water burst in from the basin and filled the lock, the water had found its way under the old sill through a sand gutter in the clay on which it was founded, and until that communication was cut off the work both within the lock and in the tidal dam could not be proceeded with.

A shaft was sunk in the middle of the old sill to the fault, and it was stopped with concrete, the outer sillwork was then proceeded with, but the stopping, although it was good enough for the head of water at low tide could not be depended on to resist the full head of a tide, consequently the inner work had to be suspended until the entrance was effectively closed against the tide.

That was done by building upon the new outer sill a temporary stank, of concrete blocks which had been made to form aprons in front of sluices and were used for that purpose later on. The blocks were bedded on mortar covered with brown paper, with a view to solid bedding without cohesion, they were set at least five inches apart and the joints at the face of stank were made good with nine inches of brickwork, set in mortar, but generally the joints were stemmed full with clay and small boulders.

The stank was built to a height of 44 feet, its base conformed to the plan of the sill, and measured 24 feet across at the side walls and 38 feet at the centre; the top width was made about 11 feet to take a service road.

With a tide at 21 feet above the Old Dock Sill, the head of water with a smooth sea was 35 feet, giving a pressure of 17·5 tons per foot lineal or 1,750 tons in all.

That pressure, however, was often exceeded in stormy weather, the stank had an open seaward exposure, and seas frequently rose nearly to the top of it and occasionally lapped over; it was perfectly tight from first to last, and when the time came for it to be removed no difficulty was experienced in raising the blocks off their beds.

They were removed, as they had been set, by an overhead steam jenny with a yoke terminating in a pair of tee ended bars, for which suitable holes had been moulded in the concrete blocks, and by putting a strain on one leg of the yoke a block would be made to part from its bed, and the second leg being hooked on the block would be removed.

For the purpose of shutting out the dock waters from the lock a coffer dam was built on the floor of lock chamber, fitted with sheet piles ready for driving, and when a berth had been prepared for it by dredging, the dam was floated out, berthed in position, and when it took the ground on a low tide, it was secured by the driving of a few piles and bolting its framework to them.

The remainder of the piles were then driven, the dam was hearted with puddled clay, and it was brought into use, the ordinary work of the dock meanwhile and until the dam was removed was carried on through another entrance.

The dimensions of the dam, of which the exhibit is a model, were length over all 160 feet, between bearings 148 feet, and its width was 22 feet at the bottom, and 10 feet at the top between walings, and its height was 38 feet over framework.

The length of the dam was divided into eleven equal spaces by twelve vertical building logs, of a side, to which were bolted eight tiers of walings; the five lower tiers were of double logs, set one on each side of the building logs, and to the latter all of the walings were bolted.

The ends were closed with 6-inch timbers laid horizontally, and ten bulkheads of 3-inch close planking connected the intermediate building logs from side to side of the dam.

Had the common form of piled coffer dam been employed it would have been necessary to run off the dock water in order to fix walings and through bolts.

The excavations for the floor of chamber at the Southern end of the lock approached within a few feet of the dam at a depth of about 10 feet below its bottom waling, and as the piles were bared they were waled and shored to the floor of chamber.

The side walls of the lock were underpinned with concrete, a considerable portion of that work was done before the old floor of lock chamber was removed by emptying cells which had been formed in the East wall, and making use of them as shafts for carrying out the underpinning work.

And it was satisfactory to find when that work was exposed by the removal of the masonry floor in front of it, that the concrete was tight up to the masonry in all cases.

The old floor of masonry was all removed, and a new floor of concrete was laid at a depth, between the sills, of 3 feet 3 inches below sill level.

The old masonry, both of the walls and the floor, was found to be very good, and the mortar well set, all of the work was thoroughly sound excepting a portion of the floor, which had been blown and allowed to remain in that condition.

The cause of that damage was apparent when excavations were extended below the foundation, uncovering water bearing strata of sand and gravel, which, in all probability, would be drained by pumps at a lower level when the masonry floor was laid, and on the completion of the job, when the pumps where removed, pressure would follow and go on increasing until the rupture of the masonry gave relief to the pent up air and water.

Under the new floor drain pipes were laid extending outwards from the pump well in a double line about 50 feet apart and connected by cross drains, at intervals along the length of the floor, and when the work was completed those drains were left free and open to the well and to manholes at junctions, the latter were covered with flags set without mortar, and the well was filled with rubble covered in part with concrete, and part with flags open jointed to give vent to water.

The deepening of the Canada, Huskisson and Sandon Docks was done by dredging after the new passages and their wing walls had been built and the old dock walls were underpinned, all of those works were carried out either within or behind dams and without running the docks dry, because the demand for dock accommodation was too great to admit of a dock being put out of use other than by a section at a time.

The new wall from the South East Pierhead of Canada-Huskisson Passage to the North West Pierhead of No. 3 Branch Huskisson Dock was constructed within a dam which was built in Sandon Graving Dock No. 6, and floated from there to the site; a plan and cross section of that dam is shown in Figs. 3 and 4, Plate V. It measured 260 feet in length, 30 feet in width, and 39 feet in depth, and was built of sawn pitchpine logs as they are imported, except that some of the logs were flat cut for the sheeting and wales.

The sheeting of dam ranged from 14-inch logs at the bottom to 3-inch planks at the top, and those timbers were laid horizontally against and bolted to 14-inch square vertical logs spaced 15 feet apart, centre and centre, a rope of cotton torch-wick was laid in each horizontal joint, and a treenail stop water was driven vertically through each butt joint; the shores abutted at each end on the vertical logs to which were bolted half-log walings immediately below the shores.

A bed for the dam was prepared by dredging to a depth of five feet below the then dock bottom, and it was grounded in position on a low neap tide and secured with a few driven piles.

Sheet piling between the vertical timbers along both sides and the outer end of dam was then driven, its inner end abutted on the old pierhead, and a number of old hopper barges were loaded and scuttled around the dam at a distance of about five feet from it; the space between the barges and the dam was filled with clay and on the end barge a framework of timber had been erected to stand well above water and serve as a guard and warping dolphin for passing vessels.

The nature of the ground to be dealt with was a light cover of marl on a thick bed of very fine sand and roach overlying red sandstone rock.

Two centrifugal pumps were at first employed to pump out the dam, and so long as there was plenty of water to deal with they did good work; there were frequent inbursts of water below the sheet piles carrying large quantities of sand into the dam, and the voids thus made were filled by the settlement of the outer wall of clay, which was replenished from time to time where soundings showed a deficiency, and the sheet piles which had been stopped by the sand were driven home to the rock when the sand was washed away from under them.

When the dam was found to hold up the water, under as great a head as could be obtained with the pumps placed above the level of the outer water, one of the pumps was fixed at a lower level and the bottom was seen for a time, but another inrush of water filled the dam and submerged the lower pump, the breach having been closed the water was again pumped out, and then the leakage was so far reduced that the pump could be run only intermittently and for a short spell at a time; as soon as the pump was stopped sand settled down upon its foot valve, and if the seal of sand could not be broken by running the pump at a high velocity it was necessary to break a joint to remove the sand, meanwhile the bottom was flooded and while it could not be drained it remained a quicksand in which the men sank to their knees, occasionally they had to be dug out and when they were required to get away in a hurry, on the breaking in of water, they often left their long boots fast in the sand.

Chain pumps were then fitted up and got to work, the sand was scuttled to them and speedily removed by them, a good working bottom was soon obtained, and although several other inbursts of water occurred, they did not cause any serious delay to the work because the chain pumps soon cleared out the sand which was washed in. The log sheeting piles were found not to be effective for keeping out fine sand and a row of 3-inch sheet piles was driven inside of them and the space between the two lines of sheeting piles was filled with clay, the top of which was made to serve as a water course to carry upper leakage clear of the foundations to the pumps.

The work then progressed satisfactorily to its completion, the dam was removed and its sides taken separately were used again as dams for the removal of some of the old walls of Canada Dock.

From the Western end of the above new wall to the West wall of

Huskisson Dock a coffer dam, 260 feet in length, similar in construction to that used at the Canada Dock, was berthed, and under cover of that dam the new Canada-Huskisson Passage was constructed.

A dam 360 feet in length was also built at Sandon Graving Dock for the underpinning of the Northern portion of the West wall of Canada Dock, it was similar in construction to a side of the Huskisson wall dam and carried its shores in place when it was floated from the Graving Dock to its berth.

The dam was ballasted at its lower edge so that it floated nearly upright, and by means of wire tripping ropes attached to the bottom edge, and head lines, worked in conjunction with the rise and fall of the dock water, it was berthed with its shores bearing against the wall, and was secured by driving a few of the piles and bolting it to them.

Following the driving of the sheet piles, clay was deposited outside of the dam, and by means of a culvert in the wall leading to the river, water was run off from between the dam and the wall, and when all was made tight communication with a chain pump well was opened, and the excavation was proceeded with.

The underpinning there was for a deepening of the dock to the extent of nine feet at the wall, the old wall foundation was on the last of the boulder clay, which in some cases was only a few inches in thickness and below lay sand, gravel and marl, and on marl the new foundation was laid.

The work was carried out in lengths of 15 feet at a time, and no exceptional difficulty arose until a bed of very fine sand about eight feet in thickness and quick with running water was met with, it was passed through, however, without any mishap, although the bottom of the wall from front to back was exposed to view for a length of 60 feet before any concrete could be got in at the first 15 feet of that length.

The sand simply flowed and carried away the timber sheeting as it was being put up, but ultimately, when the back of the foundation was reached at the starting end, it was sheeted horizontally with planks backed with rubble stone, from which drain pipes were led to the outside to carry off the water, and the concrete underpinning was got in, the wall showed no sign of having yielded beyond a hair crack which extended upwards from its foundation for about six feet.

That dam was used again, but without sheeting piles, for the

removal of another cant of the West wall, behind which a new wall had been built following the alignment of the underpinned portion.

The mode of construction adopted in that dam was found to be open to improvement, the horizontal sheeting was too stiff to readily follow the settlement that occurred where bad ground was met with, and the sheeting piles of whole logs, driven from above water, were found not to be as effective for keeping out water as plank sheeting piles driven after a dam was pumped out.

For those reasons, and because a graving dock was no longer available for dam construction, later works were carried out with dams built on the dock quays, in sections of from 80 feet to 120 feet in length and having a vertical sheeting bolted to horizontal walings.

The walings were of 14-inch square logs, and the vertical sheeting was of 11-inch timber, all of sawn pitchpine.

In building a section of a dam the walings were set up on packings at a suitable height above the quay, and on top of them the sheeting logs were laid with their bottom ends set to a straight line, they were not cut to a length but were arranged so that the longest logs were about evenly spaced in order that there should be a short bearing for any planking that might be required to cover gaps, left by short logs, below the highest possible water level.

An end log was then bolted in place and V shaped fillets of yellow pine, as shown in Fig. 5, Plate V, were nailed, one on each joint face of the logs, and they were closed up, three or four logs at a time, with hydraulic jacks, so as to make watertight joints.

Back straps were laid on top of the sheeting logs over the walings, and all three timbers were bolted together; the back straps were of 3-inch pitchpine planks, excepting that short logs were used to cross the butts of the walings.

That form of dam is readily built and easily handled, it is pliant, longitudinally, and conforms to depressions at its bed, the fillets are effective in making the joints watertight, and even after a dam has been much knocked about and strained in use, should seam leaks occur they may readily be stopped with ashes thrown into the water, which find the leaks and get trapped by the fillets in the seams.

Many of those flitches of dams have been used five or more times, and when there was no further use for them as dams their timbers made good shores and walings for trench work.

At the Huskisson Dock the underpinning of walls had to be of a depth sufficient to admit of a deepening of the dock at the toe of wall from 7 feet below to 22 feet 6 inches below Old Dock Sill below that

datum. The original dock bottom sloped upwards to the wall 2 feet from a parallel line 20 feet out from the wall, but the present bottom carries its depth right up to the wall as is required for the modern build of ships.

Figs. 1 to 7 inclusive, Plates III and IV, represent a section of that work at the North wall of No. 3 Branch Huskisson Dock at several stages of its progress from start to finish.

Fig. 1, Plate III, shows the old masonry wall as it was built, and the original formation of the dock bottom; the pile shown in front of wall is one of a number that were driven on the line of dam 12 feet apart, centre and centre, for the dam to bear against and to receive the shores from wall.

In the early stages of the work the only available lifting appliances were derrick barges of comparatively small power; and when a section or flitch of a dam, after it was launched from the quay, lay flat upon the surface of the water, it was necessary, in order to rear that flitch on edge and place it in position, to assist the barges by weighting the flitch at its lower edge. That was done with concrete blocks attached by means of long chains to the top of dam, as shown on Fig. 1, Plate III.

When, however, a powerful floating crane could be had the operation was easily performed, with a wire rope bridle attached by a pair of sling chains to the tops of sheeting logs at about one-fourth of the length of flitch from each end, the crane would rear a flitch on edge and plant it in position in a very short time.

The face of the upper portion of the wall has a batter of half an inch to a foot, and to that batter the piles were driven, the lengths for the shores were measured by a diver and they were framed together, weighted with chains and lowered into position as shown in Fig. 2, Plate III.

When the required length of dam was erected the ends were closed with sheet piles, and filling pieces against the wall, the inner face of dam having been made flush with the front walings, and clay was deposited outside of the dam to cover the lower portion more or less according to the nature of the ground.

The next operation was to get the pumps to work to pump out the dam, and while that was being done inbursts of water were not uncommon until the clay took the place of underlying porous ground. On the dam being pumped out the stiff batter and off set at the lower portion of wall was dressed back to the same plane as the upper portion, except at the ends of shores, plank sheeting piles were driven

first at the front to secure the dam and then at the back against the wall as soon as it was dressed down.

Those sheeting piles were driven home at once, if the ground was suitable, otherwise they were driven a little in advance of the excavations, the neighbourhood of the pumps would be the first to be excavated in order to get the pumps below foundation level to keep the dam generally free from water.

Fig. 3, Plate III, shows a trench in front of the wall excavated to the required depth and with the concrete apron laid, it also shows a vertical log planted in the concrete of apron and shored at the top to the face of wall in order to give support to the outer walings of trench so that the two upper shores to those walings may be removed.

Fig. 4, Plate IV, shows those shores and the upper half of the inner row of sheeting removed, and a heading to the back of the wall excavated, sheeted, waled and shored to the front of trench.

Fig. 5, Plate IV, shows the excavation under the wall completed and the concrete underpinning put in to within about four feet of the bottom of the masonry wall.

Fig. 6, Plate IV, shows the underpinning completed, the top layer of concrete was put in behind the rough rubble walls which are shown, commencing at the inside wall it was built up as the concrete was filled in behind until the top was reached and the concrete then was rammed home, and so with the other two walls and at the outer portion where concrete was filled in behind planks which were built up one at a time against profiles, in advance of the concrete, to form the wall face.

The dotted lines below the section show the maximum depth of foundation at that wall.

Fig, 7, Plate IV, shows the completed wall with the dam removed, the coping raised two feet and the dock bottom dredged to the required depth.

6-inch earthenware pipe drains were laid in the upper lift of concrete to the back of the wall, generally at every third bay of the underpinning, to relieve the ground at the back of water, rubble stone was packed about the inner end of those drains, and clay stops were put in to prevent the water following to the next working.

The work at Sandon Dock was carried out with the dock pumped dry.

The total length of underpinning work done at the Canada, Huskisson and Sandon Dock works is about 10,000 lineal feet, of

which about 1,400 lineal feet was tide work, 4,600 lineal feet was done in docks full of water, and 4,000 lineal feet was done in the open with the water pumped out of dock. The greatest continuous length of underpinning work in hand at one time was 900 lineal feet at the West wall of Huskisson Dock.

The Discussion was adjourned to the next Meeting.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

NINTH MEETING—8TH MARCH, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

Mr. GEORGE HYDE was duly elected to the Society, as a *Member*.

Adjourned Discussion upon Mr. FIELDEN SUTCLIFFE'S Paper entitled—

"SUNDRY NOTES ON DOCK CONSTRUCTION,"

which was read at the Meeting on the 22nd February, 1905.

Mr. W. Brodie

Mr. WILLIAM BRODIE said—I would say, firstly, that personally I have never listened to a paper here with greater interest, not only on account of the subject matters, but on account of personal associations with the author extending over a long series of years. It is because I know the value of the information he is capable of giving that I had expressed regret at our last meeting that he had not earlier contributed in a more prominent degree to the Proceedings of this Society, and this regret I am sure all will share. Better late than never, however, and now that the ice is broken we possibly may hope in the future to have further contributions from the rich storehouse of the author's mind.

It is scarcely necessary that I should remind this meeting what a wide field of experience in dock engineering he has reaped, and while I think I may safely leave the practical points of the paper for the most part to be questioned and discussed by others, I may perhaps fitly add something to the historical sketch which the

Mr. W. Brodie

author has incorporated in his paper. I would, however, focus the light on the last three or four decades, and endeavour to illustrate some of the changes that have occurred in the Liverpool Dock Estate during that period.

I choose this time because it is over thirty years since the author of the paper first took charge of works on this side of the Mersey, and because it followed a period of comparative stagnation as regards extension of dock works in this port.

The author has not, for our edification, extracted any incident out of the closing up of the George's Basin, as he might very well have done had other matter failed him. This in itself was a very interesting work, the execution of which was entrusted to him in the early seventies. To-day, with not only the George's Basin but the George's Dock closed up, and an immense building rising from its site like a palace in a fairy tale, it seems strange that the question of whether the water communication between the George's Dock and the Prince's Dock should be severed or not should have been an important one, but the decision to close the Basin was not arrived at without much consideration and experiment.

The ultimate result was, of course, the joining of the George's and Prince's Stages by an inserted length of 500 feet; the closing of the George's Basin, and the construction of the Floating Roadway up its centre, to give an approach of easy gradient to the Stage at all states of the tide.

The closing of the George's Basin and the Seacombe Ferry Basin, where No. 3 Bridge is to-day, and the construction of the Floating Roadway, were the first of the important works superintended by the author.

These works were taken in hand somewhere about the time when the White Star Line went into Atlantic steam, and the first "Oceanic" was perhaps as eagerly looked for from the pierhead on her arrival from Belfast as the new Cunarders will be no doubt in their turn. Since then, many tides have ebbed and flowed, but there has not, up to the present time, happily, been any ebb tide in Liverpool's prosperity, but rather a continuous flow towards a high water not yet reached.

A meeting of Liverpool Engineers such as this has learnt and has no difficulty in bringing to mind the main facts of the advances made from time to time, and the principal engineering factors which have made them possible, such as the development of screw propulsion, the compounding of the steam engine, and the cheap

Mr. W. Brodie production of steel of high quality for the hulls of ships and for boilers, allowing of larger vessels and higher pressures, with improved engines and resultant economical use of fuel.

The relative proportion of sailing and steam tonnages has altered enormously, and the newer types of steamers have advanced in length, breadth, draft and tonnage step by step. One long steamer is succeeded by another longer so regularly that perhaps we lose sight of the great advances covered by a period of years such as that we are now considering, and I have thought it might be interesting to show at a glance the state of the Liverpool Docks over 30 years ago.

The cartoons which I show you were prepared in the early part of the year 1873, from actual survey of the several docks. I think you will find them more eloquent than words could be as to the pressing need of dock accommodation at that day, and this, of course, was the story they were prepared to tell.

Beginning at the South end, the Herculaneum was a half formed dock with two graving docks out of it, and from there to Brunswick there was a long stretch of vacant ground, save for one or two small docks and basins. All the South docks, right up to the George's, were crowded with shipping, so that in some it would appear as if you could cross from one side of the dock to the other on the decks of ships touching each other.

The most Northerly docks were the Canada and Canada Half Tide (now the Brocklebank), and one of the boats shown on the plan is the last survivor of the famous Atlantic paddle boats for which the Canada Dock had been constructed in 1857 as wide as 100 feet, a width which, although given to entrances at Birkenhead in the sixties for like reasons, it was not necessary to repeat at Liverpool until quite recently, when the increasing beam of screw steamers and need of convenience and expedition in docking and undocking, made it desirable to take up anew the discarded width of 100 feet.

I am not in a position to show you a similar set of plans applying to to-day's conditions, but you are generally all acquainted with the facts, and can well appreciate the immense change which has taken place in the number, character, and size of ships using the docks since the survey of 1873.

Instead of sailing and steam ships, short and of small tonnage, lying at quay berths for weeks, discharging or receiving cargo in driblets, with others outside them also working, or perhaps merely waiting for berths, you have now a great bulk of trade done in

long steamers of large tonnage, turning out cargo at such a rate as to tax the resources of the largest sheds, and putting the working of outside berths quite out of the question. Mr. W. Brodie

The longest steamer shown on the cartoon is about 420 feet. Now, the "Baltic," in regular sailing, is 708 feet, and of course other dimensions have increased immensely also. The widest beam in 1873 would, I think, be in the neighbourhood of 40 feet.

The great jump in dimensions between that time and the present has, as I have said, been reached step by step, and the great scheme of dock extension, authorised by the Act of 1873, and carried out, as regards the North portion, under the author's superintendence, provided a long length of quayage and much deeper water than any of the then existing docks in that locality.

The Langton, Alexandra and Hornby Docks were constructed on ground previously enclosed for such purposes, and, together with the improvements at the South end—the Herculaneum, Toxteth and Harrington Docks—relieved the pressure for accommodation, shown by the cartoons.

These schemes, carried out bit by bit, were scarcely completed before the demand for further accommodation became acute, and the great scheme of dock reconstruction, from which the author has drawn his modern instances, was in due course proceeded with.

It says a good deal for the foresight of the Engineers responsible for the Canada and Huskisson Docks system that the general form of these docks was found adaptable to the vastly changed conditions, and if we except the work necessary to give good straight berths at the place where the obtrusion of the Huskisson Fort had spoiled the shape of the old design, but little was required to give the necessary depths, beyond the deepening of the lock and underpinning of the walls, the details of which the author has explained so clearly.

In addition, the provision of sheds of a different type, giving largely increased floor area, has been made, and with the new branches out of Canada Dock and one out of Huskisson Dock as altered, there is now a very large extent of lineal quayage giving a sufficient depth of water and approachable through the new deep water entrances at Sandon.

While the great series of graving docks at Sandon, solid and useful, but shallow for modern needs, has been effaced, there has been provided at Canada Dock a very fine graving dock capable

Mr. W. Brodie

of taking the great "Oceanic" or even the greater new boats of which we hear.

From first to last, the cost of the works, the practical construction of which has been entrusted to the author by the Engineers-in-Chief to the Dock Estate—Lyster *père* and Lyster *fils*—amounts to several millions of pounds. As will be gathered from the descriptions given, care has always been taken to ensure thoroughly sound work.

Moreover, in the course of operations, often most hazardous in their nature and carried out by workmen who do what they are told, depending on their superiors, and without special care for their own safety, it is to be noted that serious accidents have been few and far between, testifying to great care and vigilance on the part of the author.

On a practical point, that is with regard to one of the dock walls carrying itself without damage over a very considerable gap, I may remark that in the course of some alterations at the Albert Dock Warehouses, a test of some brickwork was made by cutting out the bricks surrounding a horizontal strip of brickwork, giving a beam 12 feet on clear bearings, 14 inches deep and the thickness of the wall, 2 feet, the beam resting on its supports, *i.e.*, being freed at the ends. It was loaded on the centre with as much weight as could conveniently be put on it, amounting to 6 tons 9 cwt., and bore this for several hours without fracture, which spoke well for the quality of the old work.

Mr. Kenyon

Mr. G. C. KENYON said—I have carefully considered the subject matter of the author's paper, and although I have, admittedly, had a little experience in dock work, must say that there is nothing therein that I take exception to. I would always be content to rely on the author's opinions concerning the carrying out of dock constructive works and take as a maxim: "follow Mr. Sutcliffe's methods and one will not go very far wrong."

Dealing with the paper verbatim, however, the following points occur to me:—

I was interested to note the date of the construction of Old King's Dock, which is given by the author as 1788. I should like to know, however, from what source he obtains his information, as I am at present interested in the King's Dock, having charge of improvement works now being carried out on this site. I produce a photograph of the North East corner of King's Dock, which shows a date, "1811," cut in the rock at low level, which must have been put in when the dock was dry, possibly during construction.

From observations obtained during recent excavating operations, it is evident that there was a small dock to the Westward of the King's Dock, and I presume that this was the dock constructed about 1788. Mr. Kenyon

It is a certainty that it was constructed previously to 1809, because in that year the King's Tobacco Warehouse was opened and this covered the site of the Old Dock.

The walls of the original dock were founded on beech piles, about 12 inches diameter, driven into the sand, and I submit for your inspection a sample of the timber in these piles which were bared about three months ago, evidently having been in the ground for nearly 120 years.

The walls of the present King's Dock, all of which will disappear owing to the improvements, are founded on rock and in certain positions at a higher level than the dock bottom. This rock shows no signs whatever of decomposition, although the water had acted on its face for a period of nearly 100 years.

Whilst on the subject of King's Dock it might interest the Society generally to know that the present river wall, opposite the King's Dock, constructed, I think, about 1847, is similarly founded on beech piles. The river wall is in perfect alignment and excellent condition. It was necessary in connection with the improvements now being carried out to extend the wall Northwards. For this purpose a trench was sunk at the North terminus to about 10 feet below the base of the wall, to obtain the foundations for the extension which is founded on rock. The trenching operations caused fretting and made it possible for one to walk about 70 feet under the wall longitudinally, and the following information was obtained by this means:—The wall is founded on slabs, about 10 feet below Old Dock Sill, under which are four rows of beech piles, about 15 inches diameter at the top, tapering gradually to about 6 inches diameter at the shoe. The piles are about 4 feet 6 inches between centres, laterally and longitudinally, and are driven through sand to rock, being in an excellent state of preservation. Running longitudinally at the back of the wall there is sheet piling driven to the rock. Although such a great length had to be supported for the time being entirely by the piles, no settlement has occurred in the wall.

On page 143 is given the depth of sills in certain entrances constructed about the year 1851, and on page 145 the level of the sills, Sandon River Entrances, constructed about 1895, is given. Perhaps it would not be superfluous to bring these depths side by side for closer comparison. Taking the deepest sill in the first case and the

Mr. Kenyon deepest sill of to-day, we now have 14 feet greater depth than formerly.

On page 147 the author mentions the fact of blow pipes being used to prevent sills, &c., becoming damaged by hydraulic pressure under certain conditions. Of two lessons which I learnt years ago, one was the formula for the superelevation of rails, the other (which I could not then understand but have now learnt from experience to fully appreciate) being the danger of imprisoning water under pressure. My problem was this: how could a vertical zone of water infinitesimally narrow endanger a retaining wall when the backing itself would not do so?

Since the reading of the paper I have had a practical example of the effect of hydraulic pressure as regards masonry. In connection with the closing up of a tidal basin a town outfall sewer had to be extended to the new river wall, the new outlet being situated at that point. The wall had been brought up above tide level and formed a dam, and the basin had to be filled in gradually after the wall had been completed. In the meanwhile the tidal water entered and left the basin through the sewer, overflowing from holes which had been left in the crown for air-shafts, the air-shafts being left out for this purpose. The sewer, which is egg-shaped and has a quick fall towards the river, is about 6 feet in height by 4 feet in width and of 6 to 1 concrete. The closing length of about 20 feet of the crown had been put in, but it appeared that the lowest hole was not sufficiently large to allow of the water in the basin levelling up with the tide, and although there was only a maximum of three feet greater head in the water on the outside of the basin, this caused the concrete in the closing length of the crown to "blow up."

To elaborate on the necessity of having blow pipes, I give the following example:—Assume the foundations of a concrete sill, laid at a level of 25 feet below Old Dock Sill, to have been badly laid and the sill to be under pressure. Theoretically there would be then a cavity capable of imprisoning water. Suppose there were an opening infinitely small which allowed of the water under pressure tapping the cavity. Assuming a 22 feet tide the vertical pressure per superficial foot of the cavity would be about $1\frac{1}{3}$-rd tons. The weight of the masonry above would only represent about $4\frac{1}{2}$ cwts., being about 4 feet 6 inches thick and taking 1 cwt. to the foot. It is now evident that if blow pipes were not in, an alternative design to prevent "blows" would be most costly.

On page 147 the author mentions the advisability of tapping water-

bearing strata and allowing water to have vent under certain conditions. It is rather amusing at times on dock works when one's visitors see a great inrush of water, they appear surprised that no notice is being taken of it by those responsible for carrying out the works. One generally knows, however, whether the leakage is contained or otherwise, and woe betide the unwary if it be otherwise. Mr. Kenyon

I corroborate the author's suggestions regarding the advantages of chain pumps for dock work generally. Only recently I had some tide work to carry out, the maximum depth being about 15 feet below lowest low-water mark, spring-tides. On neighbouring works other tide work had been carried on, the pumps used being centrifugal. Going against my own experience, I argued that if it pays contractors to use centrifugal pumps then it would pay others ; the cost of placing and maintenance being so much less than in chain pumps.

About three lots of springs were lost without making much progress with our work, and ultimately I had the original pumps, of which there were three, two centrifugals, 8 inches and 10 inches respectively, and an 8-inch Mumford, removed and substituted chain pumps, consisting of two reels with buckets, 2 feet long by $5\frac{1}{2}$ inches wide, each reel being capable of discharging about $7\frac{1}{2}$ tons at 35 revolutions per minute. The reason for providing so many pumps in the first instance was, so that if any two were out of commission it was hoped that the third would take the leakage, but it invariably happened that the whole three were all choked at the same time. After placing the chain pumps quick progress was made with the work which previously had been going ahead in a most unsatisfactory manner. I was afterwards convinced that the work could not have been completed without using chain pumps. The trouble with the valve pumps was on account of a sewer discharging in the neighbourhood of the trench, the refuse from which choked the foot valves.

One great advantage of a chain pump is the facility in sinking the well, and no matter whether the strata be running sand or rock, little difficulty should be experienced. One should always allow sufficient space between the casings to enable men to work comfortably all round each bellmouth.

By putting one reel out of commission one is able to sink that portion of the well about 15 inches, men easily working in that depth of water. The casing is then lowered to the new level and put into commission again and the other casing is then dealt with similarly. By this means the pump well should be sunk at least a foot in from 12 to 24 hours to practically any depth.

Mr. Kenyon As regards chain pumps bringing up almost anything, I myself have seen a sleeper brought up from the bottom by an ordinary sized chain pump. How it passed the bellmouth is still a mystery to me. On one occasion, about twelve months after the water had been let into the Brunswick River Entrances, it was necessary to again dry the 80-feet lock. This lock, which is 240 feet in length, was found to have accumulated a depth of nearly 10 feet of sand and mud, every bit of which was scuttled to the chain pumps and brought up by them, water for softening same being obtained from the sluices.

On page 150 the author states that in tide work he often discharged the water from the pumps into culverts. One great advantage in this is that in tide work, when water is generally discharged direct from the launders on to the beach, the scour causes channels, which have constantly to be filled up by dumping clay, &c., this of course being costly. By turning the water into the culverts this expense is done away with, the outside of the culverts being designed for the purpose.

Dealing with the Canada Lock, the author informs us that after the inrush of water "drain pipes were laid extending from the pump well "in a double line about 80 feet apart." Whilst overcoming temporary difficulties I think this method forms a "wolf in sheep's clothing" for future engineers who may afterwards be lucky enough to have to carry out alterations in the neighbourhood. I recommend that all temporary drains should be sealed up whenever circumstances permit of this being done. On several occasions I have had a vast amount of trouble through old constructional drains and the like not having been closed up.

The author mentions that horizontal skin timbers were found unsuitable for dams generally, but he did not tell us what amount of yield there is in the vertical skin timbers. On the completion of work behind dams of this description, where there is a yielding foundation, it is not unusual to find four or five feet of camber in a dam.

Dealing with the underpinning on page 154, my experience is that if the work is properly carried out there is practically no deflection in walls through underpinning, the wall acting as a heavy section girder whilst the underpinning work is in progress. As regards the filling in of the new concrete under the wall, although the operation appears difficult, it is only a question of "knack," and I have little hesitation in saying that it would be difficult at any point to get the blade of a knife between the original base of the wall and the new concrete, even were it possible to open up for this purpose.

I do not adopt the author's methods in flitch dams. He advocates the use of soft wood fillets to make watertight joints between the vertical logs forming the skin. These fillets at times give a lot of trouble through blowing out. Personally I prefer half timbers for the skin, with caulked joints, the dam being more efficient as regards leakage and the first cost less. One disadvantage in this method, however, is that "once a flitch always a flitch," whereas in the author's method the skin timbers can be used for shores and other works purposes; but I venture to suggest that the author is looking too far ahead. There are still in use on the Liverpool Dock Estate flitches which the author constructed years ago, and which will, in all probability, be used when the present generation has long been forgotten. Mr. Kenyon

The author gives 120 feet as the maximum length of his flitches for underpinning purposes, but I have gone one better and used a flitch 140 feet in length.

In conclusion, I, on my part, would like to say what a pleasure it has been to us all to have had a paper of the author's experience contributed to the Liverpool Engineering Society.

Mr. Robert Brodie said—I am sure we are all deeply indebted to the author for his most interesting, historical and descriptive paper. His idea of commencing with a brief historical sketch was an excellent one, but I think it was a mistake; he should have given us an historical *and* a descriptive paper, as there is ample material for two papers, and I am quite sure he would have done both of them ample justice. Mr. R. Brodie

It is interesting to note that although shipbuilding can be traced back to the times of the Flood, the history of docks is not yet two centuries old. No doubt this is due to the fact that navigation in the early ages was confined to what were practically tideless seas.

The author tells us that Liverpool obtained an act for their first dock in 1709, and I take it this dock was completed before the Leith Dock, which he states was made in 1720, in which case Liverpool can be considered the pioneer in dock construction.

I do not agree that two pairs of gates in reversed positions, or a double acting caisson, is necessary for the safe blocking of ships in a dry dock, as, if sufficient sluicing arrangements are provided, one pair of gates is all that is necessary.

The author's description of the methods adopted to prevent accumulation of water behind dry dock walls and under the floor, is extremely interesting, and would always be effective if you could guarantee that only clean water would find its way along the drainage

Mr. R. Brodie to the sump. There is, however, considerable danger that silt would escape, thus running the risk of settlement and possible fractures. Consideration must also be given to the cost of pumping, and an engineer must consider the various circumstances of the case before deciding whether he will adopt the system described in the paper, or will attempt to seal the dock, which would reduce the risk of settlement and cost of pumping, but would necessitate much heavier construction and would greatly increase the risk of blows.

The author is in favour of the chain pump, and in certain cases I think it is the best; as a general rule, however, I prefer the centrifugal pumps for lifts up to 45 or 50 feet, and the rocker pump for lifts above that height. He enumerates the advantages to be gained by using a chain pump, but does not draw our attention to the disadvantages as compared with the centrifugal. The original cost is much higher, the necessary staging over the sump is much more expensive, the wear and tear is much greater, the liability to breakdown is also probably greater and the cost to work heavier. The author gives the work of a chain pump with a casing of 2 feet 6 inches by 6½ inches, which is apparently about equal to a 12-inch centrifugal pump. I have had considerable experience in using these 12-inch pumps with lifts up to about 45 feet, and I find that a 25 H.P. portable is easily master of the work; in fact I am to-day using a 20 H.P. portable for driving a 12-inch pump, with a lift of nearly 40 feet. I shall be glad to know what horse power is used for this chain pump.

The arrangement which was made for discharging from the pump at a level of 5 feet above O.D.S. is most ingenious and no doubt effective, but again I claim an advantage for the centrifugal. I have two centrifugals working now at Tranmere, both of which discharge into the river about half-tide level, through 12-inch pipes which are built through the concrete walls. The only additional cost here is the provision of a 12-inch sluice valve at the back of the wall. When the tide is down we get the advantage of the reduced lift, when the tide is up we simply have to pump against the pressure due to the head of water over the pipe. As illustrating the effectiveness of the centrifugal pump, I may here mention that although both of these pumps have been working continuously for about nine months, the sluice valve on each has only had to be closed once, in one case owing to a shaft breaking, and in the other case owing to our having decided to substitute a 12-inch for a 10-inch pump. I think this shows very clearly the reliability of this pump, and during an experience of some

ten years with from two to six centrifugal pumps constantly going, equal to (say) forty years of one pump, I can remember very few cases of breakdowns. I have, perhaps, had a dozen breakdowns altogether, chiefly from broken shafts, and I remember a case where a spike was picked up and got jammed between the disc and the casing. Mr. R. Brodie

The author says he abandoned the use of centrifugal pumps inside his box dam because the foot valves got choked with silt after a blow. Perhaps he did not have telescopes fitted on his suction pipes, which would provide for any ordinary difficulty, and if the difficulty were extraordinary, it would be better to stop pumping until the leakage is located and stopped.

The built dams, to which reference has been made, have apparently proved fairly successful, but I do not like them, my objection to them is the danger of blows underneath. In my experience at Canada Dock, where we underpinned some 400 feet of wall, I used single sheeting pile dams, but although these piles were driven well into the ground we had several nasty blows underneath, and I cannot understand how it is, that in the material which is described as sand, gravel and marl, under a few inches of boulder clay, they did not have constant trouble from the water bursting through underneath the dam. I do not admit that he is right in stating that it would be necessary to run off the dock water in order to fix walings and through bolts, this work should certainly be done in the dry where possible, but I have done a good deal of it under water by divers where it was found inconvenient to run a dock dry or where the work came below low water level.

In the flitch dams the author has evidently been to a large extent dependent upon his inside row of sheeting, but this could only be put in as the excavation proceeded, and cross polings would be required under the struts, an extremely difficult operation in bad ground with a big head of water outside.

The box dam, of which a model is exhibited, is an improvement on the flitch dams, in so far as the sheeting piles in each bay can be driven down, but I understand the original vertical timbers are fixtures and here you have weak points which the water will probably find out. As the strength of a chain is the weakest link, so the efficiency of a dam is the weakest point.

The case which is explained of the stank which was built with concrete blocks bedded on mortar with strips of brown paper, is a very good illustration of the advantage of having a thoroughly practical

Mr. R. Brodie man in charge of works, who is able to take all the circumstances of the case into consideration. The man who is saturated with theory would never have thought of using these concrete blocks, which had already been made and would afterwards be used elsewhere, and I am glad to think that the Dock Board recognize the author's ability and realize the value of his practical skill.

Mr. Hope Mr. ALARIC HOPE said—The question was once asked, "What is a Civil Engineer?" and the answer, given I believe, by a lady, was: "A man who knows how many pounds there are on the square inch."

This definition will no doubt commend itself to you as a complete embodiment of all that an ordinary Civil Engineer needs to know, but after hearing the author's paper, I think it will occur to most of us, that a dock engineer has to know one thing more, and that is, how to keep the water out of his works.

Apart from the historical portion, the paper deals almost entirely with the problem which, owing to the increasing draft of modern large vessels and the corresponding depths which are required in the docks and entrances, is becoming more and more difficult.

In reference to the timber dams, which the author has described, it may be of interest to deal briefly with their design from a mathematical point of view.

The amount of stress which can be allocated to the shores depends usually not upon the strength of the shores themselves but upon the crushing strength of the walings in a direction at right angles to that of the grain.

If the walings are of pitchpine this will be about 30, but if of greenheart, it will exceed 200 tons per square foot.

In practice on the dock estate the walings are usually made of pitchpine and, consequently, each shore ought not to take more than about 20 tons per square foot.

The margin of safety thus provided may appear small, but it is sufficient owing to the fact that the transverse crushing of the walings, if it takes place, is so gradual a process that it can be watched, and checked, if necessary, by the introduction of additional shores.

Having determined the stress to which each shore is to be subjected, and the horizontal distance B from centre to centre of each group of shores, having regard to the transverse strength of the walings, the vertical depth from higher water level to the bottom must be divided into zones of equal pressure.

Mr. Hope

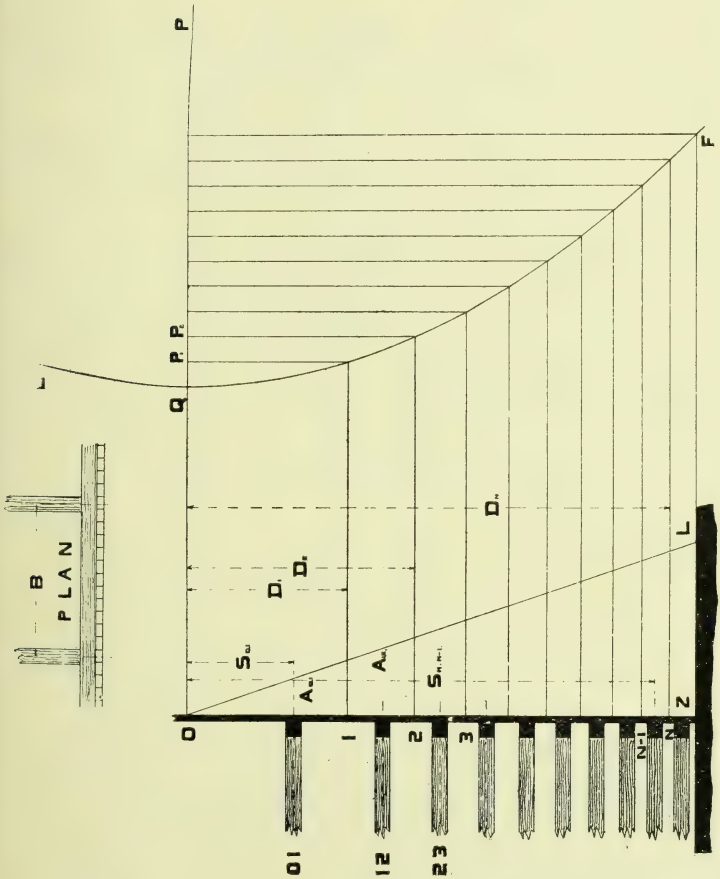
Referring to the diagram :—

Let P be the pressure allocated to each shore.

" D_1 " depth, from the water surface, of the first zone.

" W " weight of a cubic foot of water.

$$\text{Then } P = \frac{B\,D_1^{\,2}\,W}{2} \text{ hence } D_1 = \sqrt{\frac{2P}{B\,W}}$$



Mr. Hope

The depths of the bounding planes of the other zones will be as follows:—

$$D_2 = \sqrt{2}\ D_1 : D_3 = \sqrt{3}\ D_1 : DN = \sqrt{N}\ D_1 : \&c.$$

the depths being all measured from the water surface.

The zones may also be determined graphically as follows :—

Take any parabola $E\ Q\ F$ of which Q is the vertex and $O\ Q\ P$ the axis: let $O\ Q\ P$ represent the highest water surface.

Draw the line I parallel to and distant D_1 from the water surface $O\ Q\ P$.

From its intersection with the parabola, draw a perpendicular cutting the axis at the point P_1.

Set off distances, P_1, P_2, &c., equal to $Q\ P_1$ along the axis: drop perpendiculars from P_2, P_3, &c., to cut the curve and from the points of intersection draw the horizontal lines, 2, 3, 4, &c.

These are the boundaries of the zones of equal pressure.*

If taking $Z\ L\ F$ as the bottom of the water, make $Z\ L$ represent the intensity of pressure at that level, *i.e.*, $W \times O\ 2$, $O\ 2$ being the vertical depth.

Then the triangle $O\ Z\ L$ represents the pressures acting on the sheeting of the dam and the areas $A_{0\cdot1}$, $A_{1\cdot2}$, $A_{2\cdot3}$, &c., are all equal and measure the pressures transmitted to each shore.

The centre lines of these shores must coincide with the centres of pressure of their respective zones.

The depths below water level of these centres are given by the formula—

$$S\ N\ N-1 = \tfrac{2}{3}\ D_1 \left(N^{\frac{3}{2}} - (N-1)^{\frac{3}{2}}\right)$$

and work out as follows :—

$S_{0\cdot1}$	=	·667 D_1	...	$S_{5\cdot6}$	= 2·345 D_1
$S_{1\cdot2}$	=	1·219 D_1	...	$S_{6\cdot7}$	= 2·549 D_1
$S_{2\cdot3}$	=	1·558 D_1	...	$S_{7\cdot8}$	= 2·739 D_1
$S_{3\cdot1}$	=	1·869 D_1	...	$S_{8\cdot9}$	= 2·915 D_1
$S_{4\cdot5}$	=	2·120 D_1	...	$S_{9\cdot10}$	= 3·082 D_1

This formula may be used without any reference to, or definition of, the zones, but it involves the preliminary calculation of D_1.

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* For another construction *vide* Brodie on "Dock Gates." Transactions of Liverpool Engineering Society. Vol. XVIII.

Shores whose positions are ascertained by the use of it will be stressed equally when the surface of the water is at its maximum height. Mr. Hope

The same formula is applicable to the design of caissons, dock gates, cofferdams, and the timbering of excavations through uniform material.

To understand the problem, however, a consideration of the zones is necessary, and by plotting them the calculated positions of the shores may be checked.

The dam shown in section has a depth below top water level of 39 feet 9 inches of salt water; the horizontal spacing of the shores is 12 feet centre to centre, and the load on each shore (14 feet by 14 feet pitchpine) is 27 tons.

I should like to ask the author what are his views as to the horizontal pressure which is capable of being exerted by puddled clay against a vertical surface.

I believe that in more than one case the transverse ties of double-skin dams containing puddled clay have given way owing to the clay having transmitted a greater conjugate pressure than was anticipated, and I shall be glad to know what are the author's opinions on the subject as the result of experiment or experience.

Theoretically clay can produce horizontal pressures equivalent to those which would be transmitted by fluids weighing anything between (say) 20 and 70 pounds per cubic foot, according to its angle of repose as affected by its wetness; then, again, very heavy pressures are sometimes met with, especially in tunnelling work, which are due to expansion of clay caused by exposure to a moist atmosphere. After puddling, however, further swelling would hardly appear to be possible.

The subject is one of some importance as influencing the cost of very expensive though temporary structures.

Mr. James Glover said—I am afraid I can add nothing to the discussion of this paper, because it appears to be almost above criticism. We ought, I think, to admire not only the subject matter, but also the great literary merits of the paper. Mr. Glover

Like Mr. R. Brodie, I am rather puzzled to know how it was the author had so comparatively little trouble with his flitch dams resting on such soft strata—the clay fillet, however, may have been greater than shown on the diagrams.

I have in use at the present time about 300 feet of skin dam consisting of singly driven grooved piles with iron tongues; the piles

Mr. Glover are driven some ten feet below the river bed in good clay, but even this depth has not prevented two "blows" under a head of 25 feet of water. I should also be glad if the author could give some idea of the cost of the flitch dam as compared with that of a singly driven skin dam.

Mr. Pain Mr. Coard S. Pain said—I quite endorse the remarks of the last speaker as to the literary merits of the paper. It does not often happen that men are both very literary and practical.

I want to ask the author one question. Looking at the diagrams, one is prompted to suggest that either the original retaining wall was too thick at its base or the underpinning of it was not thick enough. One notices that the original wall is stepped and gets thicker at the base, but the stepping ceases where the underpinning commences.

It is easy to understand that extending the width of the wall beyond the original width would be a difficult operation, and this may be the answer to the question.

Mr. Boscawen Mr. P. N. Boscawen said—Mr. Kenyon's observation as to the wear of sandstone leads me to remark on the very variable quality of some of the red sandstone beds, even far below the surface.

In a length of 30 feet of foundation I have found the sandstone was excessively hard at each end, while in the centre, with apparently no reason, it was so soft as to be almost capable of being cut out with shovels.

I have noticed also that the effect on some of this sandstone, of exposure to air and water, for short periods, varies considerably; the bottom of a foundation, comparatively hard immediately after excavation, has become soft on the surface after a day or two's standing while exposed to air and water. On the other hand, stone which has stood for some time, is often said by masons to have become tougher and harder to work than the "green" or freshly quarried stone.

Mr. Sutcliffe Mr. Fielden Sutcliffe, in reply, said—Mr. William Brodie, in opening the discussion, gave me a few sly digs which seemed to indicate that he thought I had been an unprofitable member, slow to contribute, of my experience, to the Proceedings of the Society.

I must admit that I have done but little in that direction, and I can only plead, as my excuse, that the works on which I have been engaged, generally, have been carried on at high pressure and have pretty fully occupied my time.

Mr. Sutcliffe

It has, however, frequently been my privilege to show visitors, including many members of this Society, over those works, and I have felt that I could better describe a work at its site than at a meeting such as this.

I am indebted to Mr. Wm. Brodie for his kind pertinacity in bringing me up to the scratch on this occasion and for his valuable assistance.

His brilliant synopsis of the changes that have been wrought in the Liverpool Dock Estate during the last 30 to 40 years, was, I am sure, highly appreciated by all who listened to him.

I have to thank Mr. Robert Brodie for having noticed that I omitted to give the date of the opening of the Old Dock at Liverpool. It was opened in the year 1715.

Mr. R. Brodie does not agree with me that for a graving dock entered from a tide way there is a need for either two pairs of gates, in reversed positions, or for a double-acting caisson ; but although I am aware that there are cases in which such provision is not made, I think it is all important to be in a position to retain water in a graving dock until blocking and shoring operations are completed, in order that it may be used freely, to the best advantage, and with safety.

Contrasting chain pumps with centrifugal pumps, Mr. R. Brodie said of the former, "The original cost is much higher." I grant that, but would add so also is the efficiency ; he said "the necessary staging "over the sump is much more expensive," but that remark does not apply where pumps are placed at dams which extend above high water level, or at deep trenches, because in such cases the only extra would be the lander, and at tidal dams the cost of the staging would be more than covered by the advantage of having the steam engine above water.

He further objected that "the wear and tear is greater," and I agree with him as regards the pump but I consider the reverse to be the case with the actuating steam engine.

He said, "the liability to a breakdown is also probably greater." That, however, is contrary to my experience ; I have in my mind the case of a set of three chain pumps employed at tide work for a period of over three years, during which time there was neither a breakdown nor a failure to act when required of any one of the three pumps.

He also said that "The cost of working is greater." I agree that the cost of attendance may be greater but the expenditure of power would be less.

Mr. Sutcliffe

Mr. R. Brodie enquired as to the power required to drive a chain pump having a casing 2 feet 6 inches by 6½ inches in cross section.

At the latest tide work carried out at the Canada Basin three such pumps with a maximum lift of about 32 feet were driven by a 40 H.P. semi-portable engine; at the Canada Lock and at several of the dock wall underpinning works, two pumps of that size were driven by a 40 H.P. engine, where the lift would be about 50 feet.

The low level pump, at the box dam, to which Mr. R. Brodie referred, was a 15-inch centrifugal pump; he is under a misapprehension as to the cause of the abandonment of that pump; it was given up because it failed to act when required to work intermittently. I may add that a telescopic suction pipe was used but that it did not meet the difficulty, because with sand, set hard, under a considerable head of water, resting upon the clack it could not be opened until the foot valve joint was broken and the sand was dug out.

Of the chain pumps employed at that job there was only one case of a breakdown, which was caused by a quantity of sand and several pile shoes being washed into the mouth-piece of the pump.

Similarly, at the adjacent underpinning work, a chain pump was choked by a quantity of sand and bricks having been washed into the sump, and in that case, in order to clean out the sump, a centrifugal pump was employed to deal with the water, but it was so frequently stopped, owing to its foot valve failing to act, that no headway could be made and the chain pump had to be made to free itself; that was done by hauling around, backwards, the chain of buckets, by means of a steam crane, reeving a suit of well worn buckets, from a smaller sized pump, in lieu of the original suit of buckets, and then driving the pump at a high velocity until the sump was freed of many tons of sand and quite a cart load of bricks.

The difficulty of preventing water blowing through beneath the built dams has in practice proved to be not nearly so great as Mr. R. Brodie and Mr. Glover appear to imagine it would be; a reasonable cover of good tough puddled clay, placed at the lower edge of a dam, was generally sufficient to exclude water; occasionally there would be a blow through; but a further deposit of clay at the point generally met the difficulty and admitted of the plank sheeting piles within the dam being driven, and they being kept well in advance of the excavations were effective in keeping out the water.

To Mr. Glover's enquiry as to the relative cost of these flitch dams and an ordinary sheet piled dam, I would say that if the dam covers the whole of the work to be done, the latter form would, probably,

be the cheaper in most cases; but that the flitch dam has a decided advantage when, as in this case, there were a succession of dams and the flitches were used again and again, many of them five or six times, and their vertical sheeting logs having only two bolt holes in each log, were useful timbers at the finish of the work; whereas sheet piles used there were frequently unfit for driving a second time. Mr. Sutcliffe

In reply to Mr. Kenyon I have to say, that an official record gives the year 1788 as the date of the opening of the King's Dock, and that the figures 1811, which he has found graven on the rock face below a wall of that dock, may possibly mark the date when it was deepened.

Mr. Hope asked for my views as to the horizontal pressure of clay puddle against the sides of a coffer dam.

On that point I am not in a position to give definite information, but I may say that I should expect the greatest pressure to obtain immediately on the clay being filled in, because its settlement would then be in the most active stage; and I should look for a gradual diminution of that pressure, consequent on the consolidation of the clay puddle, provided there were no disturbance of the ground below the lowest transverse ties of the dam.

But should any such disturbance take place, as may happen when excavations are carried on in the ground immediately behind a dam, an undue strain may be thrown upon the lower ties and, should they give way, upon those above, carrying them away in succession.

If the filling in of clay puddle be done slowly and evenly throughout the whole area of a dam, lurching of clay in mass would be prevented and horizontal pressure would be very materially less than would be the case if the work were done in haste and unevenly.

Mr. Hope said—"Theoretically clay puddle can produce horizontal "pressures equivalent to those which would be transmitted by fluids "weighing anything between (say) 20 and 70 pounds per cubic foot, "according to its angle of repose as affected by its wetness."

But the maximum measure which he gave appears to be based on an angle of repose of 45 degrees, while clay puddle if dumped into water would flow at a much smaller angle, and in that soft state the horizontal pressures it would produce would, I think, be more nearly represented by those which a contained fluid weighing 100 pounds per cubic foot would exert.

Mr. Hope spoke of heavy pressures due to expansion of clay caused by exposure to a moist atmosphere, but of such I have had no

Mr. Sutcliffe experience, and as regards boulder clay it commonly dries and cracks on being exposed to the atmosphere.

Mr. Pain suggested that the underpinned wall as shown on diagrams appeared either to have been too broad at its base originally or to be too narrow when underpinned, but the conditions are not the same, the old wall was founded on clay or other yielding soil, while the underpinning is founded on rock or hard roach immediately over rock, both of which are practically incompressible.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

TENTH MEETING—22ND MARCH, 1905.

FRANK E. PRIEST, M. Inst. C.E.,
PRESIDENT, IN THE CHAIR.

The following gentleman was duly elected to the Society, viz. :—
Mr. C. D. SAMPSON, as a *Student.*

ELECTRIFICATION OF RAILWAYS.

BY H. W. WILSON, A.M.I.E.E.

THE subject with which this paper proposes to deal is such an exceedingly large one, that the general outline can only be briefly indicated, but it is proposed to pay special attention to some of the later developments, which may be of interest to the Society.

Speaking broadly, the railways in this country may be divided into two classes—

(1) Suburban lines.

(2) Main lines.

The suburban lines have to transport a very large number of passengers, and require, at certain times of the day, a very frequent service. The main line railways run a number of passenger trains, but rely upon goods traffic for the greater proportion of their receipts.

It is obvious, from the nature of things, that the suburban lines present the easier problem from the electrification point of view, and will derive the greatest advantage from such conversion. The electrification of main trunk railways is in a state of scientific discussion and little actual work has been done up to the present time.

It is proposed in this paper to outline various methods of the electrical operation of railways which can be adopted, and to consider briefly their applicability to the varying conditions to be met.

Leaving out of consideration for the moment the different methods of generating energy, and taking only the motor equipment of the vehicles, it is possible to work a railway on either the direct current system or the alternating current system. For alternating current working it is possible to adopt either a three-phase motor equipment or one of the various forms of single-phase motors which have been developed during the past two or three years.

Considering the methods of generation and use together, it is possible to have :—

(1) Plain direct current generation and distribution, which can be used for short lines, such as the Mersey Railway and the Overhead Railway in this city. A modification of this is found in the three-wire system adopted on the City and South London Railway, which is described in the Appendix.

(2) Three-phase generation, with sub-station conversion to direct current by means of rotary converters, which is the system adopted by the Lancashire and Yorkshire Railway Company for the line between Liverpool and Southport; by the North Eastern Company for its electrified line at Tyneside, and by various of the Underground Railways.

(3) Three-phase high tension generation and transmission, with low tension three-phase distribution from transformer sub-stations, as in the case of the Valtellina Railway and other lines on the Continent.

(4) Three-phase high tension generation and distribution to the lines, with the use of high tension motors, which has been tried on the Berlin-Zossen Military Railway.

(5) Single-phase high tension generation and transmission, and low tension distribution from transformer sub-stations to single-phase motors.

(6) High tension generation and distribution feeding directly to high tension single-phase motors.

As regards the methods of supplying the energy to the motors it is possible to use either :—

(1) A third-rail equipment, in which the running track is bonded and used uninsulated as the return, the current being conveyed through the third insulated rail and collected by a slipper.

(2) A four-rail equipment, with an insulated rail, both for lead and return.

(3) An overhead conductor for supply, having the current collected either by a trolley or bow, and using either the bonded running rail or an insulated third rail for return.

(4) More than one overhead conductor used with bow collectors.

The first system, which is used on the Liverpool Overhead Railway, is a familiar one and used only for direct current.

The second, which is the system adopted on the Mersey Railway, could be used either for direct current or comparatively low voltage single-phase alternating current.

The third has a similar application but can also be used for high tension work.

The fourth system is used for polyphase alternating current working.

Having stated briefly these facts about the arrangements of the various systems it becomes necessary to consider their limitations in application.

The direct current system of supply, with either plain direct current generation or conversion from alternating current, has, until recently, been regarded as the only satisfactory method of operation, and some large schemes have been carried out with various arrangements of direct current apparatus. The main reason for this has been the admirable features from a traction point of view of the series direct current motor, which has been developed both in itself and in the methods of control adopted into one of the most perfect arrangements of apparatus conceivable.

In this motor the torque developed decreases with increase of speed, and inversely with increase of load the speed of the motor decreases. The maximum torque of such a motor occurs in starting. The best makes of direct current traction motors will stand tremendous overloads without serious sparking, and their operation is simple and easily learned.

Most direct current traction systems have a supply of energy to the motors at a pressure of about 500 to 600 volts, though large machines have been built for pressures up to as high as 1,000 volts. Beyond this pressure, however, it seems practically certain that commutation trouble would arise, and it is therefore fairly obvious that on a heavily loaded section of line the current capacity of the conductors and their consequent cost would be prohibitive, or else a very great line drop of voltage must be permitted at times. Also, the cost of a complete direct current system of distribution with alternating current generation, converter sub-stations and feeders, is very heavy per mile of track, and the traffic receipts of some lines would not warrant the expenditure required.

For these reasons experiments were made by many firms to en-

deavour to devise some satisfactory methods of alternating current operation of railways. Three continental firms—Messrs Ganz, of Buda-Pesth, Siemens and Halske and the A.E.G., of Berlin—devoted great attention to three-phase traction systems with considerable success. The chief drawback of the various arrangements devised by these firms, apart altogether from the complication of overhead conductors, which on a main line railway would be a fatal objection, lies in the inherent characteristics of the motor itself. The characteristic of the polyphase induction motor is essentially that of a constant speed shunt wound direct current motor : that is, it can only operate efficiently over a certain limited range of speed, and when operating below this normal range of speed it is less efficient. That is to say, that when caused to operate at below its normal or approximately synchronous speed by the insertion of a resistance in the secondary circuit the motor merely wastes the power corresponding to the difference between its normal speed and that actually run at. In other words, the induction motor consumes at low speed the same power which it consumes at the same torque at full speed, though the power output is reduced in proportion to the speed.

It is apparent, therefore, that there is an ample choice of systems, and as all have been proved practicable in working under their own conditions, it becomes necessary to consider the merits of each system for use in this country.

Before proceeding further it will, perhaps, be advisable to point out that the electrification of a railway is not, as some people appear to imagine, as simple a problem as the electrical operation of a tramway system. Between them there are many points of similarity, but in the electrification of a railway there are a number of difficulties which are not felt to the same extent on a tramway system. On a large traction system the variations of load on the generating station are comparatively small, owing to the large number of cars usually in operation, and the comparatively small demand for energy which any car makes. In the case of an electrically operated railway system, the number of units (taking the standard size train as a unit) is, however, much smaller than on a car system, and owing to the higher speed schedule required it becomes necessary that the acceleration shall be much greater, and this, coupled with the increased weight of the units, shows a much heavier demand for power upon the station. Under these conditions it is apparent that the fluctuations of load upon the engines will inevitably be severe, and that the variation of voltage drop which will obtain along the line will be a point

requiring very careful consideration. These points are now being emphasised, perhaps unnecessarily, as they have considerable bearing on some of the later remarks.

As just said, there seems to be an expectation amongst those who have not considered the question carefully, that all that is required for the electrification of the entire railway system of this country is a simple extension of the present, somewhat glorified, tramway lines, of which we have examples in this neighbourhood. This idea is certainly doomed to disappointment, as the systems already laid down, both in London and in this district and on the Tyne, do not represent ideal arrangements for main railway traffic, and it is, in fact, open to question whether they are the best possible arrangements for short and busy lines. It is conceivable that in a comparatively few years they may be regarded as interesting survivals of obsolete systems which have been superseded by more satisfactory ones.

The various systems that have been laid down in this country up to the present are in most cases direct adaptations from American standard practice, which means that the original American idea of making an electric railway into an enlarged tramway system has been regarded as the course to be followed. On the Continent, where there is a tendency at all events to approach problems of this nature more in a spirit of scientific enquiry, and also in the States, where the limitations of what has previously been regarded as standard practice are now being recognized, there is a distinct leaning in favour of some form of alternating current working. In this country, however, we are now in a position to take advantage of the experience that has been gained from the various experiments made abroad, and it would be a very desirable thing if the railway companies could mutually agree upon the lines on which the electrification of their systems should proceed, if, and when, carried out, so as to permit of the interchangeability of vehicles on the different systems of route. It is obvious that if the different companies adopt all manner of electrification systems, voltages, arrangements of trolley wires and live conductors, interchangeability and joint running will be practically impossible. It seems fairly certain that within a comparatively short space of time now sufficient experience will have been gained to enable a decision to be come to as regards the main important points in considering the problem, and one of the objects of this paper is to endeavour to point out to some extent some of the electrical considerations which are controlling factors in the situation.

Apart altogether from electrical considerations is the very vital

one of capital cost, and in this connection it might be pointed out that on the Central London Railway the total expenditure per mile of route comes out at something of the order of £500,000 per mile. The capital expenditure on railways in Great Britain and Ireland per mile of route, irrespective of the number of tracks, is at the rate of £45,300. This shows that the proportionate outlay on the generating station for a main line railway is a very much more serious item than it is in the case of a tube or very expensive suburban railway. Also, as previously pointed out, the traffic density on the main line railway is usually much less than on a local line. The working costs of some railways were, in 1900, 36·84 pence per train mile, and the cost of locomotive power represented about 11½d. of this total.

The success of the electrification of main line railways would have to depend upon its ability to reduce the train mile costs, as the questions of acceleration, speed of running, &c., which are all important on short passenger lines, do not matter very greatly in the other case; that is to say, the question of overall efficiency of distribution is very much more important on main than on urban lines.

Considering these positions logically, it is obvious that below a certain traffic density the electrification of a railway cannot possibly pay, as it is essential that the load factor on the generating station shall be kept fairly high.

ACCELERATION.

In short lines with a large number of stops one of the main advantages of electrical operation is the high accelerations and retardations possible. As far as economy of time is concerned, on a line with a number of stops, the higher the acceleration and retardation, and the higher the speed of steady running, the more satisfactory is the service. The possibilities of increase of acceleration in practice is limited, on account of discomfort to the passengers, by the increase of cost; not merely in energy actually consumed but also the capital cost of the plant required at the generating station to take the peak caused; and also by slipping which sometimes occurs. The maximum speed is also limited by cost, not so much on account of the energy taken while running, but on account of that demanded during acceleration, as the time of running at maximum speed is limited.

The accelerations possible with a steam locomotive, even when specially designed, are comparatively low, and can easily be beaten by

a good electrical equipment. The best results obtained in practice of which the author is aware are those of the new equipment of the Liverpool Overhead Railway, and the following table shows a comparison between the running obtained of the new equipment as compared with the old on that line. As will be shown later in the paper, however, a comparatively small proportion of the energy supplied from the generating station to the line in this railway is employed in the useful work of actually driving the train.

TABLE SHOWING
RESULTS ON THE LIVERPOOL OVERHEAD RAILWAY.

	Old System	Accelerated Service
Mean Speed	12½ miles (20 km.)	19½ miles (31 km.)
No. of Stops	16	16
Mean Time at Stations	11 seconds... ..	11 seconds
Mean Distance between Stations ...	729 yards (666 m.)	729 yards
Watt hours per ton mile	110	137
Acceleration	1·6 foot per second^2	3 feet per second^2
Retardation	3 feet per second^2	4·7 feet per second^2

ALTERNATING CURRENT SYSTEM OF TRACTION.

In considering the question of polyphase electric traction, it will be a convenience to outline briefly what has been done so far in this direction, and for this purpose it is proposed to give some details of three typical lines, all of which are fairly well known. The first of these lines is the Berlin Zossen high speed military railway; the second, the Valtellina Railway in Northern Italy; and the third, the Burgdorf-Thun Railway in Switzerland. As this latter line was the first to be opened, it will perhaps be well to consider it first.

The Burgdorf-Thun Railway is a full gauge line, 25·5 miles long, over which ordinary steam engines and rolling stock can pass. It is worked electrically by three-phase current, transmitted at 16,000 volts from the power house, 5½ miles distant, on the Kander at Spiez. This current is transformed down to 750 volts at 14 transforming stations along the line. Some of the cars are automobiles, seating 66 persons each, on bogies fitted with induction motors, and are electrically lighted and heated. For train service Messrs. Brown, Boveri & Co., who constructed the entire electrical equipment, have built two locomotives, each having two induction motors of 150 H.P.

each, or 300 H.P. for each locomotive. Each locomotive weighs 28 tons, 10 tons of which is for the electrical equipment. The speed is regulated by a variable resistance in the rotor circuit. This line has two overhead trolley wires, and uses the rails as the third conductor.

The Berlin Zossen High Speed Military Railway, which is in some respects the most interesting electrically operated railway in existence, is the result of the work of two well-known German manufacturing firms: the Allgemeine Electricitats Gesellschaft, and Siemens & Halske, who, in their work, had the support of the German Government. A number of experiments were made at Marienfeld with cars running up to about 50 or 60 miles an hour, and after this the construction of the main line was planned. This line was designed for very high speed traction, and a number of interesting points in connection with track construction, weight of rails required, &c., were discovered, but those do not particularly affect the scope of this paper. It was arranged that a speed of 200 kilometers—120 miles per hour—should be the maximum at which the cars were to be run. The supply is given at a pressure of 10,000 to 12,000 volts, with three overhead conductors. The supply is given by the Oberspree Central Station at Berlin, the distance from the central station to the nearest point on the line being about 9½ miles. In the first cars transformers were fixed to reduce the pressure of supply to the motors down to about 435 volts, but in later cars the high voltage supply has been taken to the motors directly, in order to avoid having to carry the weight of the transformers on the car. The motor cars accommodate about 50 persons each, and the motors themselves are capable of working up to a maximum of 3,000 H.P. when accelerating and 1,100 H.P. with normal running. The car is started up with a liquid resistance in the rotor circuit, the starting arrangements being of a novel plan, whereby the liquid is pumped into a suitable tank and the resistance gradually reduced. The total weight of the electrical equipments of some of the first cars made was 47,600 kilograms, but owing to the special construction of the motors their weight was reduced to 28·7 pounds per H.P. for their nominal output and 9·5 pounds per H.P. for their maximum output. It is apparent from the arrangement of starting apparatus described that the starting of these cars will be very smooth, as there is none of the jerkiness observable similar to that when a controller handle is put over from one point to the next, and what is perhaps even more important, the number of cable connections required is reduced to a minimum. The current is led to three wires placed vertically one above another, from which it is taken

into the cars through bow shaped collectors. A number of experiments had to be made before it was found possible to get a suitable construction of trolley bow to collect the current at the high speeds of running of this special case. The cars are carried on two bogies 43 feet 7 inches apart, with 49 inches diameter wheels. The speed of the motors is about 960 revolutions per minute. All the electrical apparatus of the car is most efficiently earthed, so that there is no danger whatever to the driver or passengers. The Berlin Zossen line is, of course, practically straight, as it would be impossible to run at the speeds of those vehicles round anything like a sharp curve. According to the latest information the line is operating most satisfactorily. The braking is done by separately exciting and short circuiting and reversing the motors.

On both of the railways described above, the disadvantages of the plain three-phase motor equipments are apparent, as no attempt has been made to get over the difficulty of the poor starting torque and low efficiency at low speeds of the three-phase induction motor. On the Valtellina Railway now to be described, Messrs. Ganz of Budapest have used a system which appears to be the only one whereby a three-phase motor equipment can compete with a direct current one for ordinary traction working. In their arrangement, each car is carried on two bogies, and each bogie is mounted with two motors, each rated at 150 H.P., but two of the motors on the cars are only used during starting and take the place of a large portion of the usual starting resistance. The motors are all of the three-phase induction type, the armatures being of the squirrel cage pattern, with all conductors fully enclosed in tunnels in the iron. When the train is running at its normal speed only two of the motors on each car are in use, these two together being rated at 300 H.P. At starting, however, the other two motors are brought into use in the following manner. The supply service at 3,000 volts delivered to the stator of the driving motor generates, by means of its revolving magnetic field, currents in the rotor of its own motor at 300 volts pressure, and at starting this 300-volt current is delivered to the stator winding of the second motor. The revolving field produced by this current in the second motor starts up its rotor, so that at starting, instead of one motor on each bogie only being in service, two motors acting on two axles are performing work in getting up the speed of the train. The speed at starting is necessarily lower than the normal running speed, and when half normal running speed has been attained, the second motors are cut out, and the current from the rotors of the main

driving motors is diverted to resistances provided for the purpose which are gradually cut out in the usual way as the train gets up speed. The current generated in the rotors of the second motors when in operation is also passed through resistances provided for the purpose. The resistances are somewhat similar to those used on the Berlin Zossen line, being of the liquid type, and having the fluid, which is a solution of sodium carbonate, forced into resistance tanks by means of compressed air as required.

The arrangement of the motors as described above, which is known as the "cascade" or "concatenated" system, is also used for braking purposes, the two motors acting as dynamos in the usual manner. It is stated that the accurate control of the resistances which can be obtained with this system enables the torque of the motors to be maintained constant during the whole time of acceleration.

The above outlined arrangement represents the nearest approach to the series parallel control of direct current machines which can be obtained with a three-phase equipment.

The passenger trains are designed to run at 39 miles per hour on all gradients under 10 per cent. Above that the speed is halved, the cascade arrangement of motors being again brought into use. For goods traffic the running speed is 20 miles per hour, and the freight locomotives are designed to draw loads of 250 tons at that speed. The motor carriages are designed to carry 60 passengers and two tons of luggage, and weigh 54 tons each unloaded. They are 62 feet long between buffers.

Two trolley wires are used with the rails as the third conductor, and the trolley wires are carried at a height of 19 feet 8 inches above the rails, except in tunnels, where the height is reduced to 14 feet 9 inches. The trolley wires are doubly insulated; they are suspended by specially strongly constructed insulators, consisting of iron petticoats with Ambroin insulation, and the insulators themselves are suspended from steel wires which are insulated at their supports, the poles on the open line and the masonry in the tunnels.

The total length of the line is 66 miles, and the output is furnished by falling water taken from the river Adda. The power station is situated at Morbegno, the canal conveying the water being between two and three miles long, the available fall being 98 feet. The quantity of water available is said to be 35 cubic metres per second, which would give a gross horse power of nearly 13,000. There are four turbines in the power station each capable of exerting 2,000 horse power when supplied with water at the pressure described,

directly connected to four three-phase generators, which supply current at 20,000 volts, 15 cycles. The energy is taken from the power house to ten sub-stations, which are placed at distances of about 6·2 miles apart along the line.

At the sub-stations the energy is taken to stepdown transformers and the line supplied at 3,000 volts. The transformers in the sub-stations are of a capacity of 450 kilowatts each.

There are four trolley bows on each car: two to each overhead conductor, one at the front and one at the rear of the car. The overhead conductors are each carried at the same height and parallel with each other.

The concatenated system of three-phase traction outlined above was the one advocated by Messrs. Ganz for the Metropolitan and District Railways before the Parliamentary Committee considering the electrification of these lines. As is now ancient history, after very prolonged consideration it was decided to adopt three-phase generation and transmission with converter sub-stations and supply to the lines.

The above brief descriptions outline fairly well what is being done in polyphase railway working, and whilst the lines described are operating successfully, it is obvious that there are numerous objections which have been referred to in other parts of this paper.

GENERAL CONSIDERATION OF THE REQUIREMENTS TO BE MET.

Having considered briefly the various systems, the requirements to to be met in the electrical operation of railways may now be stated.

(1) For the operations of main lines, in order to avoid heavy transmission losses or impossible capital expenditure, it is necessary to use extra high tension generation, with transformation at sub-stations along the line. If the sub-stations are to contain converting machinery with the necessary skilled attendance, they must be kept as few as possible, although this means increased transmission losses on account of the greater length of feeders. It will, therefore, obviously be more satisfactory to use sub-stations simply containing ordinary transformers.

(2) In view of the fact that the capital and running cost of converter sub-stations renders their use impossible, it is apparent that the use of alternating current with comparatively high voltage supply to the trains is essential.

(3) The foregoing consideration makes it apparent that the use of overhead conductors for the supply of energy is necessary, as it would

be impossible in this country to efficiently insulate conductor rails at high pressures.

(4) It is exceedingly important and desirable that the train equipments should be such that interchange of vehicles with their varying equipments between the different lines be possible.

Considering the above-named conditions it is apparent at once that we are compelled to consider either the single phase or the polyphase alternating current systems of railway working, and the inherent defects of the polyphase system, from a railway engineer's point of view, practically puts this out of court. In spite of the ingenuity and resource of the engineers who have directed their attention to overcoming the difficulties of three-phase railway working, it is still impossible to get as satisfactory results from any combination of three-phase motors as can be obtained from the direct current system and series parallel control. Even were this not so, the complications caused by the necessity of using at least two overhead conductors completely bars the system from a practical point of view on a crowded railway. We are, therefore, at once driven to the consideration of the single phase equipment, and it will be interesting to refer briefly to the various suggestions on this point that have been brought forward by various firms and persons.

In a paper read before the Institution of Civil Engineers by Messrs. Mordey and Jenkins, in the beginning of 1902, after considering the matter they concluded that single phase working was inevitable, but, at that time, a really satisfactory single phase traction motor was not upon the market, and they were therefore compelled to consider a very interesting system proposed by Mr. Ward Leonard, which has many features of interest, but which it is now hardly likely will ever be used upon an extensive scale.* Mr. Leonard suggested using single phase generation and supply to the line, and that the locomotive of the train should carry a motor-generator set consisting of a single phase synchronous motor directly coupled to a direct current generator. The line supply might be fed directly to the motor or pass through a transformer as was found desirable, and the direct cnrrent supply from the generator could be taken to direct current motors fitted in the ordinary way. By the variation of the strength of field of this generator a varying direct current voltage could be

* It may be pointed out, however, that the Oerlikon Co., of Switzerland, are experimenting with this system, and that the results they have obtained are sufficiently satisfactory to justify the expectation of its being used in special cases.

obtained, so that it would be possible to start up the motors without controllers with a large current at a small voltage, and to gradually bring the field strength of the generator up, thus increasing the voltage and the speed of the motors as the acceleration of the train proceeded. A small single phase induction motor was provided to bring the synchronous motor up to speed before switching on to the line, and also for driving a small direct current dynamo for exciting the synchronous motor and possibly for other purposes as well. It is obvious that the equipment cost of a train of this type would be very

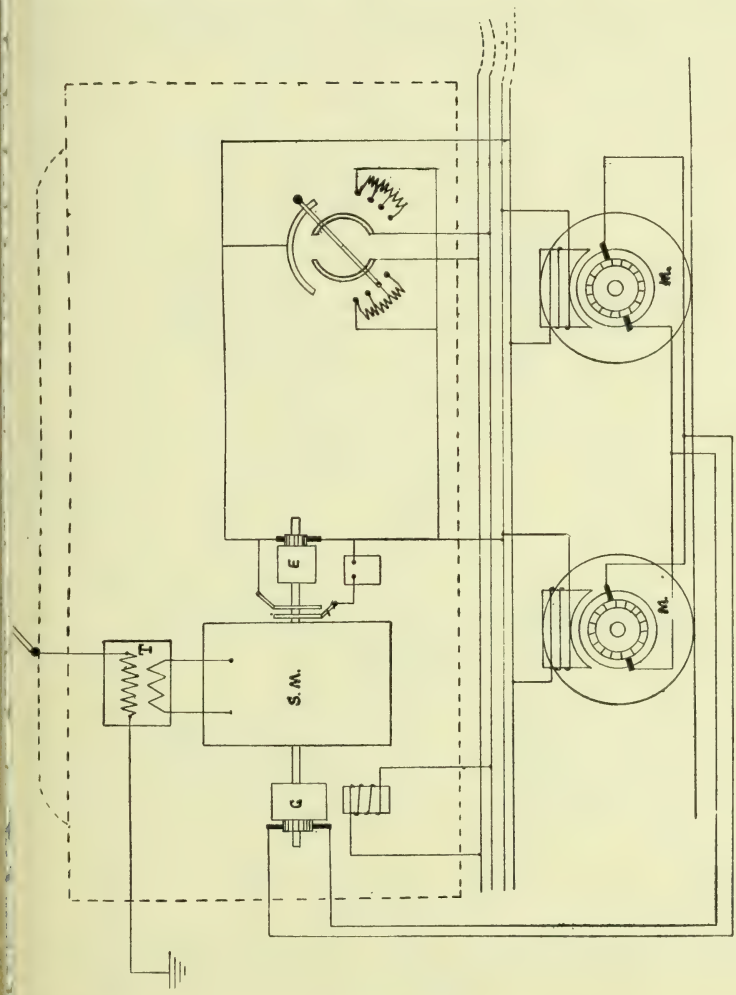


DIAGRAM OF WARD LEONARD SYSTEM.

DIAGRAM 1.

heavy, but it would be economical in working, as the demand for energy on the generating station during acceleration would be kept small, as no power need be wasted in heating up resistances. The diagram which is given here of the arrangements suggested is entirely self-explanatory.

Another ingenious system which was suggested before the development of the single phase traction motor was that proposed by Mr. B. J. Arnold, who suggested the use of a combination of an induction motor with a mechanical energy storage contrivance, the device consisting of an air compressor and a tank. In this system, both parts of the motor are free to rotate and maintain a constant relative speed.

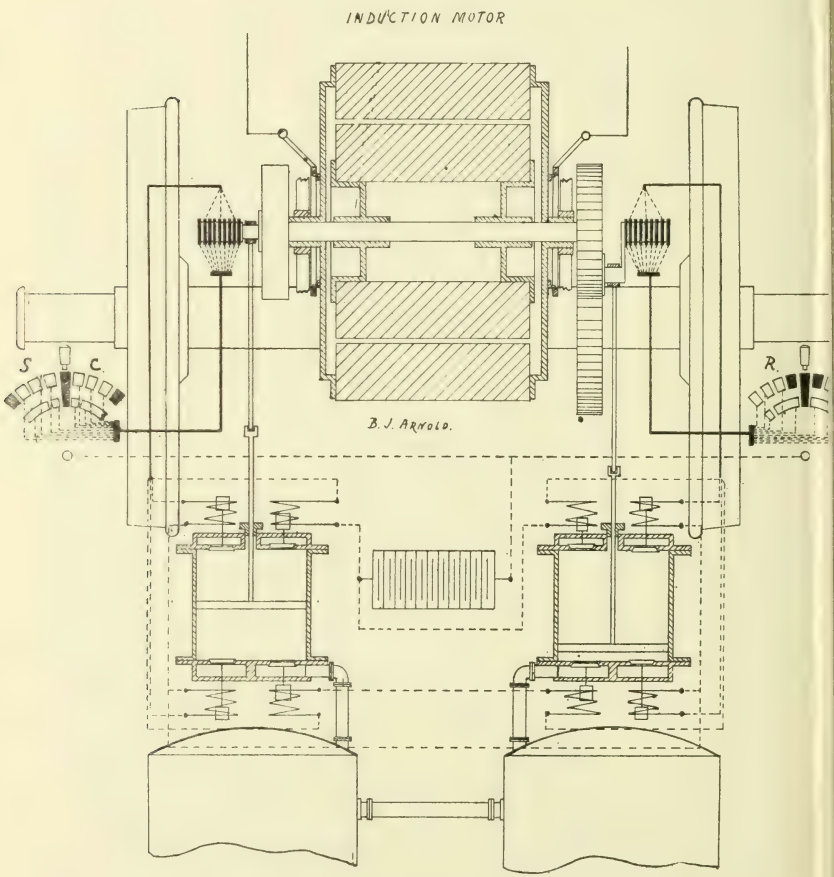
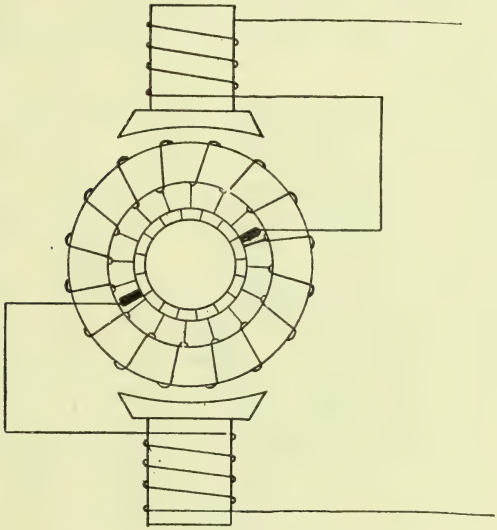


DIAGRAM 2.

The rotor is geared to the axle and also connected to one air cylinder. The stator is connected to a second air cylinder in which, when the car is running at less than full speed, air is compressed. When the car is at full speed, the stator is at rest and there is no compression. By admitting air to this cylinder and rotating the stator in the same direction as the rotor, the car can be run at more than synchronous speed. This combination, with the induction motor continually running, makes it possible to store energy when the car is coasting or stopped, and to use this energy when the car is being accelerated. In addition, this system allows the operation of the car by compressed air for a limited time, should it be desirable, to run without the overhead conductor. Details of the efficiency of this arrangement are not available, because, so far as the author is aware, it has never passed the experimental stage. It was proposed to fit one line in the States up on this system; it may, however, now probably be regarded as a candidate for the rank of a museum curiosity.*

We have now, therefore, to consider the three types of single phase traction motors which have been developed during the past two or



LAMME – FINZI

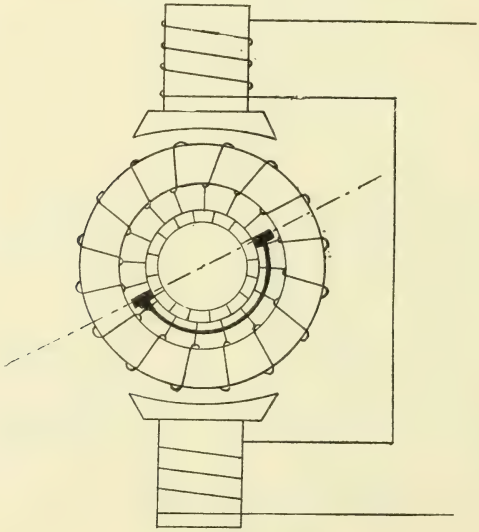
DIAGRAM A.

*A locomotive to Mr. Arnold's design was built for the St. Louis coasting line in the States, but was unfortunately destroyed by fire recently before its trial run.

three years, and which may be called the series motor, the repulsion induction motor, and the repulsion series motor.

The alternating current series motor was proposed by Messrs. Lamme & Finzi, and which is manufactured by the Westinghouse Company, is shown diagrammatically (diagram A), and possesses the characteristics of a direct current series motor. It is, therefore, directly applicable to railway work. As shown in the figure, the current passes in series through the field and armature windings. The armature is of the ordinary direct current type with commutator, and the fields are entirely laminated. As the direction of rotation in the direct current series motor is not dependent on the direction of the current, it is evident that the motor will operate with alternating current as well as with direct current. It will be apparent that, on account of commutator difficulties, very high pressures cannot be used with such a motor as this, and it is therefore necessary to have a stepdown transformer on the car if the line voltage is high.

The repulsion induction motor, as developed by Messrs. Steinmetz and Schuler, and which is manufactured by the General Electric Co., in the States, is shown in Diagram B, and whilst its characteristics are in many ways the same as those of an ordinary series motor, it



STEINMETZ — SCHÜLER.

DIAGRAM B.

can be operated on high pressures, because, as is apparent from the diagram, the armature is independent from the field system. The current is induced in the armature by a transformer action, and can be of any desired pressure. The brushes are short-circuited and placed at an angle to give the best running conditions.

The repulsion series motor, shown in Diagram C, was designed by Winter-Eichberg, and is built by the Union Electric Co., Berlin. This motor is similar to the repulsion induction motor with the addition of a second set of brushes displaced 90 degrees from the short circuited brushes as shown. Through these brushes current is supplied by a series transformer. This is done for decreasing the sparking at less than synchronous speed, and secures the important additional advantage of raising the power factor nearly to unity.

REPULSION SERIES MOTOR.

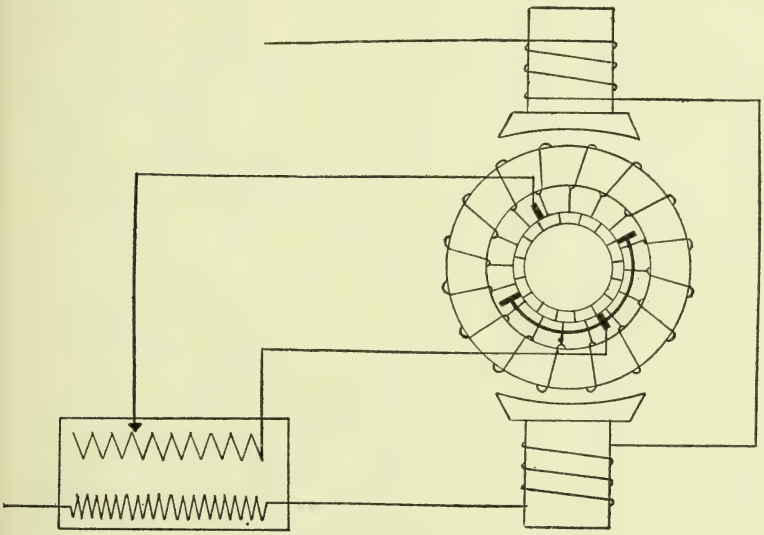


Diagram C.

In general, the operation of all three motor systems is effected by master controllers arranged to give the desired combinations. To obtain the voltage variation for speed control, induction regulators are used in all three cases, thus avoiding losses due to rheostatic control in each case.

It seems reasonable to assume that one or other of the repulsion type of motors is the one that will be more generally used, and concerning these machines it may be said that the motors have the same characteristics as the direct current series motor, namely, maximum torque at starting, decrease in torque with decrease in current and increase in speed, and comparatively constant efficiency through a wide range of speed. The maximum speed of the motor is limited only by the load and the impressed voltage, and has no relation to the synchronous speed. Due to the reactance of the motor circuits the power factor at starting is low, and will be with any alternating current motor, but in the repulsion motor a low power factor does not mean a small torque. On the contrary, the maximum torque occurs simultaneously with the lowest power factor, *i.e.*, at starting. The power factor of the repulsion motor rises very rapidly with the speed; it reaches a good value at one-third synchronous speed, and values of nearly 90 per cent. are obtained over a considerable range of speed. For this reason a large number of poles are not necessary, and frequencies up to even 60 cycles may be employed. The rotating conductors of the secondary cutting the primary flux generate a leading E.M.F., which causes a leading current to flow therein and gives the high power factor of the motor. In the plain repulsion motor this leading current does not reach a high enough value at variable speeds to compensate entirely for the wattless currents, but the addition of the second circuit in the series, or compensated, repulsion motor makes it practicable to use larger clearances than would be possible with the ordinary induction motor, and this is a great convenience for railway working. The motor efficiency, while not so good as the direct current motor efficiency, is satisfactory, reaching values of 80 to 85 per cent., including gear losses, for motors ranging from 50 to 200 H.P. At normal speeds, commutation is very good, due to the revolving field. As the speed decreases, the current increases rapidly, producing a tendency to spark, but with the reduced voltage of starting, the rush of current is limited to values within the range of good commutation, as in the direct current motor. At higher speeds, ranging above 50 per cent. over synchronous speed, the frequency of commutation becomes high and sparking occurs.

The Diagram No. 3 shows the characteristics of the motor very clearly. These curves are taken from tests on a 60 H.P. 25 ~ 500 volt motor. They show the rapidly rising efficiency and power factor and the large torque at starting. The staring torque is 2,300 foot-pounds with an input of 325 amperes, and the normal torque during

acceleration is 450 foot-pounds at 750 revolutions and 125 amperes. Thus, the starting torque is five times normal, and the starting current 2·6 times normal; or the torque per ampere at starting is 1·92

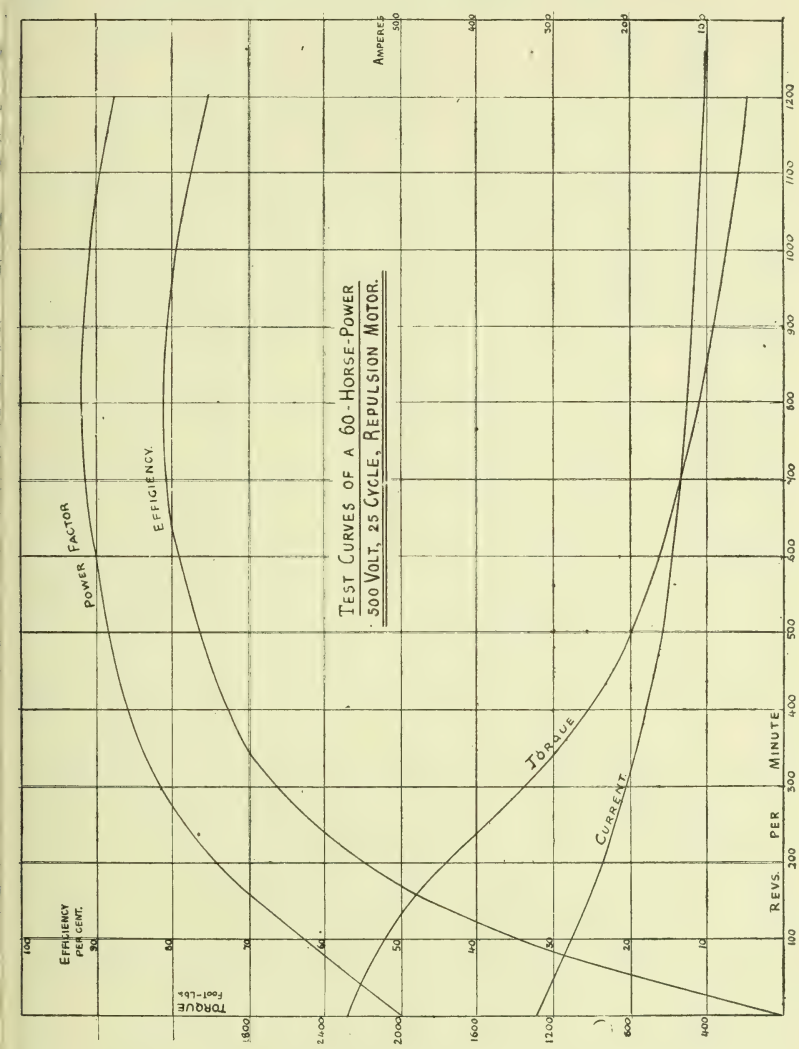
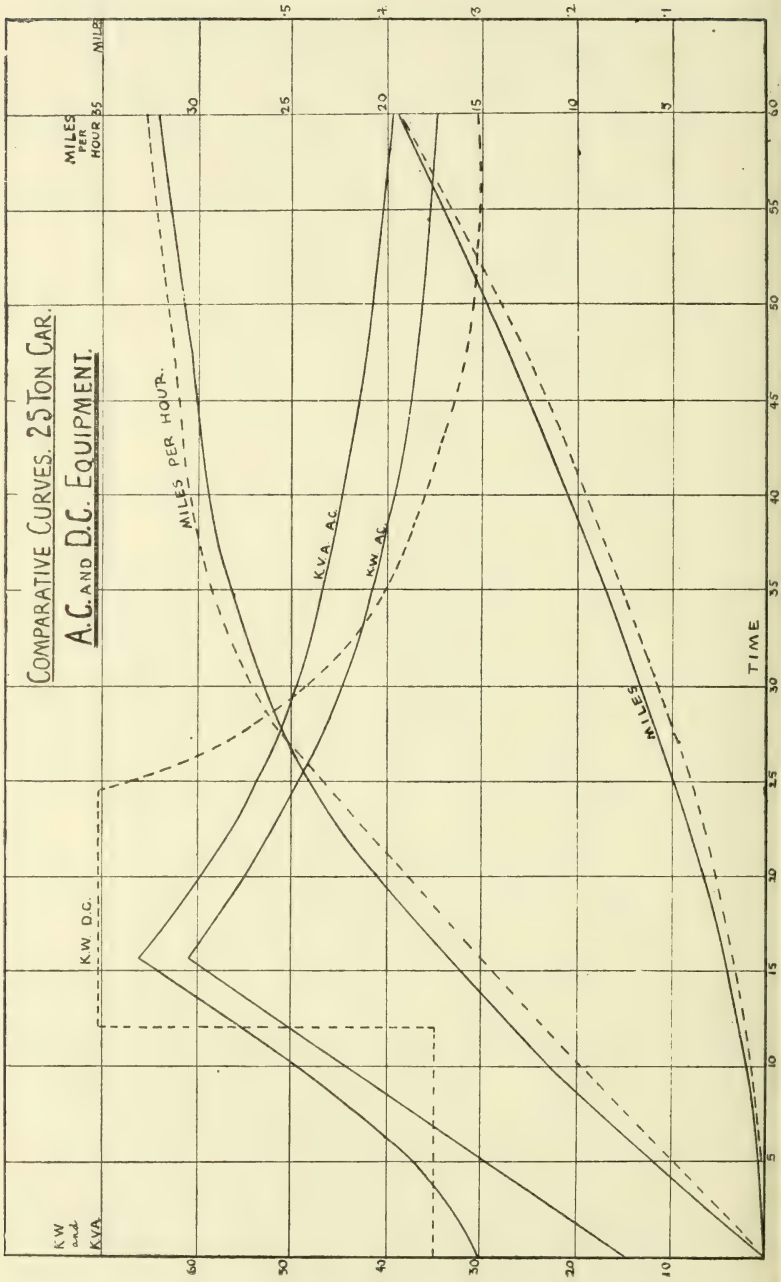


DIAGRAM 3.

times what it is at normal speed should occasion demand the full starting capacity of the motor. The motor of Fig. 3 will start at 75 per cent. of full voltage and twice full load current with no trouble


COMPARATIVE CURVES. 25 TON CAR.
A.C. AND D.C. EQUIPMENT.
KW and KVA
MILES PER HOUR
MILES
TIME
KW D.C.
MILES PER HOUR.
KVA AC
KW AC
MILES

from sparking. As these curves are prepared upon a traction motor basis, and full load current will produce a rise of 75 degrees Centigrade after one hour's run, the ability of the repulsion motor to successfully commutate overloads is really better than that of the direct current series motor.

In Fig. 4 are shown the acceleration curves from the tests of a car equipped with 2·60 H.P. repulsion motors. As a comparison, the curves of a direct current equipment arranged for the same running speed are also given, with the same average acceleration and the same distances covered in 60 seconds. The full lines represent the alternating current curves, the broken lines the direct current, and from these figures the advantages of the repulsion motor equipment are evident. It is very noticeable that the maximum power demanded by the alternating current system is considerably lower than by the direct current. This is a very valuable property, in that it reduces the maximum demand upon the generating station.

From the above particulars briefly given it is apparent that the single-phase traction motor has now reached a degree of satisfactory performance which brings it within the range of practicable use for railway work, and that being granted, it will be advisable to consider the probable comparative costs of equipment as compared with the standard direct current system. Various provisional estimates have been drawn up in America giving these comparative figures, and in a calculation which was given by Mr. Blanck before the American Institution of Electrical Engineers in an article on Single-Phase Railways he prepared some figures which are given herewith. (See pages 202 and 203.)

The more favourable capital cost shown with the alternating current system is due almost entirely to the great reduction in the sub-station costs and the reduction in the weight of copper in the trolley line. It has been assumed that the alternating current motor equipments will cost one-third more than the direct current, which is a very liberal allowance. It was assumed in making these calculations that the line was 60 miles long, single track, between towns; that there were five local cars having a one-hour headway and running at 25 miles per hour and taking 144 units for the run; one express car making the round trip in three hours and having a schedule speed of 42·8 miles per hour and taking 231 units for the trip. The power house is placed about the middle of the line and contains one sub-station, four sub-stations being located at equal intervals along the line. A direct current voltage of 650 volts was assumed, and an alternating current

Table I.

Estimated Cost of the Electrical Equipment of a 60-Mile Track Inter-Urban Railway.

	Direct Current System	Alternating Current System
Power House—		
Buildings	£2,000	£2,000
Foundations	500	500
Boilers and Settings	2,400	2,400
Steam Piping and Covering	1,500	1,500
Engines	4,400	4,400
Generators, two 400 K.W.	3,600	4,600
Exciters	200	200
Step-up Transformers, 800 K.W.	1,600	1,500
Switchboard	700	600
Wiring	600	500
Feed-water Heater	160	160
Pumps	160	160
Coal Storage	200	200
Smoke Stack and Flues	400	400
Fuel Economisers	600	600
Stokers	700	700
Incidentals	880	880
Totals	£20,600	£21,300
Sub-Station in Power House—		
Building Extension	£200	£120
Synchronous Converter, 300 K.W.	960	—
Transformer, 300 K.W. Alternating Current	640	400
Switchboard	400	260
Wiring	200	100
Incidentals	120	40
Totals	£2,520	£920
48-Mile Transmission Line—		
Poles charged to Trolley Line	—	—
Copper	£2,000	£2,300
Insulators, Pine and Cross-Arms	1,500	1,000
Erection	800	600
Incidentals	200	200
Totals	£4,500	£4,100
Sub-Station along the Road—		
Building	£400	£200
Synchronous Converter	960	—
Step-down Transformers	640	400
Switchboard	400	260
Wiring	200	100
Incidentals	100	40
Totals	£2,700	£1,000
Four Sub-Stations	£10,800	£4,000

TABLE I—*Continued.*

ESTIMATED COST OF THE ELECTRICAL EQUIPMENT OF A 60-MILE TRACK INTER-URBAN RAILWAY.

	Direct Current System	Alternating Current System
TROLLEY LINE AND FEEDERS—		
Poles, 3,500	£3,500	£3,500
Erection of Poles	800	800
Guides and Anchors	400	400
Brackets, with Hangers	3,600	5,000
Copper, Direct Current—		
Feeder, 12 miles, 500,000 cir. mils. ...	—	—
" 48 miles No. 0000	—	—
Trolley, 120 miles No. 000	19,000	—
Alternating Current—		
Trolley, 60 miles No. 00	—	4,300
Feeder Insulators	400	—
Erection	2,000	800
Incidentals...	1,500	800
Totals	£31,200	£15,600
BONDING OF RAILS—		
Both Rails Bonded	£6,000	—
One Rail Bonded	—	£3,000
Cross Bonds	400	200
Totals	£6,400	£3,200
ROLLING STOCK—		
Ten Vestibule Passenger Cars, weighing about 30 tons, with four Motor equipments ...	£15,000	£17,000
Two Express Passenger Cars, weighing about 35 tons, with four Motor equipments ...	3,600	4,100
Two Luggage Cars, 30 tons weight, with four Motor equipments	2,000	2,400
Snow Plough and Repair Car	1,400	1,700
Totals	£22,000	£25,200
RECAPITULATION—		
Power House	£20,600	£21,300
Sub-Station in the Power House	2,520	920
Transmission Line	4,500	4,100
Four Sub-Stations along the Road	10,800	4,000
Trolley Line and Feeders	31,200	15,600
Bonding of Rails...	6,400	3,200
Rolling Stock	22,000	25,200
Totals	£98,020	£74,320
Cost per Mile	£1,633	£1,238
Saving per Mile	—	£395
Approximate saving = 25 per cent.		

voltage of 3,000. The line drop for 300 K.W. in either case is as shown on the diagrams. The decrease in the total capital costs shown in the alternating current system is about 25 per cent., and this would permit of the electrification of a line which would otherwise not pay for the interest and repayment charges demanded.

The figures given are, of course, the most detailed that are at the author's disposal, and while it might quite reasonably be argued that they are for a comparatively small local line with an intermittent service, it should be pointed out that the comparative economy would certainly be even more marked for a longer line with greater inherent transmission losses. For such a line it would be possible to work at very high transmission pressures between the main station and the sub-stations, and on a shorter line with a greater traffic density, whilst the saving in copper might not be so high, the reduction of the sub-station capital costs and running expenditure would be such as to make an exceedingly favourable comparison possible.

LOCATION OF POWER HOUSE.

The question of the location of the main generating station is a very important one, and the author is personally inclined to the opinion that the best results could be obtained in districts where the number of lines is considerable, by the various companies arranging to work joint power houses. It would not seem impossible for arrangements of this kind to be come to, whereby each company would pay for the energy actually consumed, upon a scale of charges and maximum demand, &c., previously drawn up. It is fairly obvious that on some lines fluctuations in demand would be very considerable, and the capital cost of a power station capable of taking the peaks might be very heavy. The greatest objection to the arrangement suggested appears to be the difficulty of obtaining way leaves for the underground cables or overhead conductors carrying the energy from the main generating station to the various sub-stations, and this, of course, is a point that would require very careful consideration. At the same time, however, it does not seem impossible that a working arrangement could be arrived at.

An interesting and suggestive development in this connection is, that the Walker Wallsend Power Company at Newcastle are supplying the North Eastern Railway with the energy required for the electrified portion of their line at Tyneside. In this case, of course, the power station is placed very conveniently for the railway, and although such a condition might not always exist, it is conceivable that various Railway Companies might come to terms with the large Power Supply

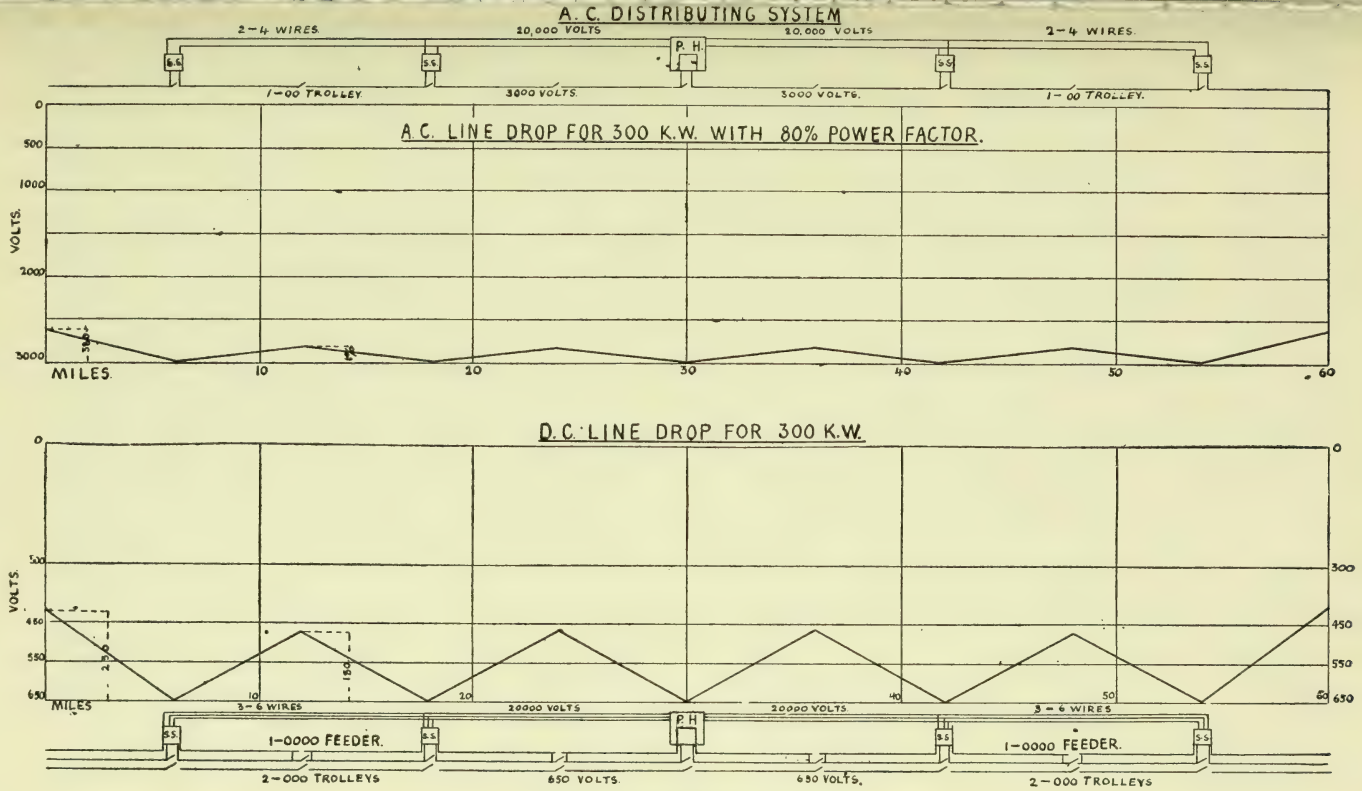

A. C. DISTRIBUTING SYSTEM
2-4 WIRES.
20,000 VOLTS
20,000 VOLTS
2-4 WIRES.
P. H.
S.S.
1-00 TROLLEY.
3000 VOLTS.
3000 VOLTS.
1-00 TROLLEY.
A.C. LINE DROP FOR 300 K.W. WITH 80% POWER FACTOR.
VOLTS.
0
500
1000
2000
3000
MILES.
10
20
30
40
50
60
D.C. LINE DROP FOR 300 K.W.
VOLTS.
0
500
450
550
650
300
450
550
650
MILES
10
20
40
50
3-6 WIRES
20000 VOLTS
20000 VOLTS
3-6 WIRES
P.H.
S.S.
1-0000 FEEDER.
1-0000 FEEDER.
2-000 TROLLEYS
650 VOLTS.
650 VOLTS.
2-000 TROLLEYS
D.C. DISTRIBUTING SYSTEM.

DIAGRAM 5.

Companies for the energy required for their lines. A somewhat important advantage of this arrangement would be that it would reduce the increased capital necessitated for the conversion of the lines.

RETURN DROP OF VOLTAGE IN RAILS.

A point which does not always receive the attention which it merits in considering questions of railway electrification, but which is really a governing factor of the possibility of such a scheme, is the consideration of the return drop of voltage in the rails under working conditions. From Diagram 5 shown on the preceding page it is apparent that the calculated drop of voltage at the mid point of a section at times of maximum load with an ordinary direct current 650 volt system is very large indeed, and a great portion of this drop is due to the rails themselves. In this country, of course, the Board of Trade requirements as to the drop of voltage in insulated bonded return track, have to be met, and in some cases it has been found desirable to use a fourth insulated rail to act as a return conductor, as the question of electrolytic action need not then be taken into consideration. Speaking generally, it may be estimated that the ohmic resistance of a bonded railway line is about ten times as great as that of a copper track of the same sectional area. This is somewhat higher than is represented by the specific resistance of the two metals, and is accounted for by the fact that the bonding of the rails does not give quite the same result as if the metal were continuous. When, however, the fact is taken into consideration that an electrically operated train similar to those of the Lancashire and Yorkshire Railway, takes 1,500 to 2,000 amperes during acceleration, it is evident that the drop of voltage is bound to be something very considerable. A little consideration will show that for a long railway track, unless the number of feeding points allowed for is very large, and the consequent cost of feeders almost prohibitive, it will be essential to raise the line voltage above the Board of Trade limit of 650 now in use. As previously pointed out, with a direct current equipment, a very large increase of line voltage will be difficult on account of troubles with commutation. With an alternating current system this difficulty does not occur, and the line voltage could be raised very considerably. A further difficulty, however, now crops up, which is, that the apparent resistance of the rail track with alternating current is very considerably greater than the actual ohmic resistance, on account of the fact that the current

density is not the same over the whole area of the rail, but is much greater on the outside portion. This skin effect when the cross sectional area of the rail is large becomes a very serious factor, and in an iron rail is further complicated by the varying magnetisation set up by the alternating current. It is obvious that this impedance effect will vary with the periodicity, and the lower the periodicity the lower will the apparent resistance of the track become, but the exact degree of this variation for different current densities has not been very carefully worked out yet. On the Burgdorf-Thun Railway, some experiments which have been made show that the apparent resistance of the rails at a periodicity of 40 cycles and

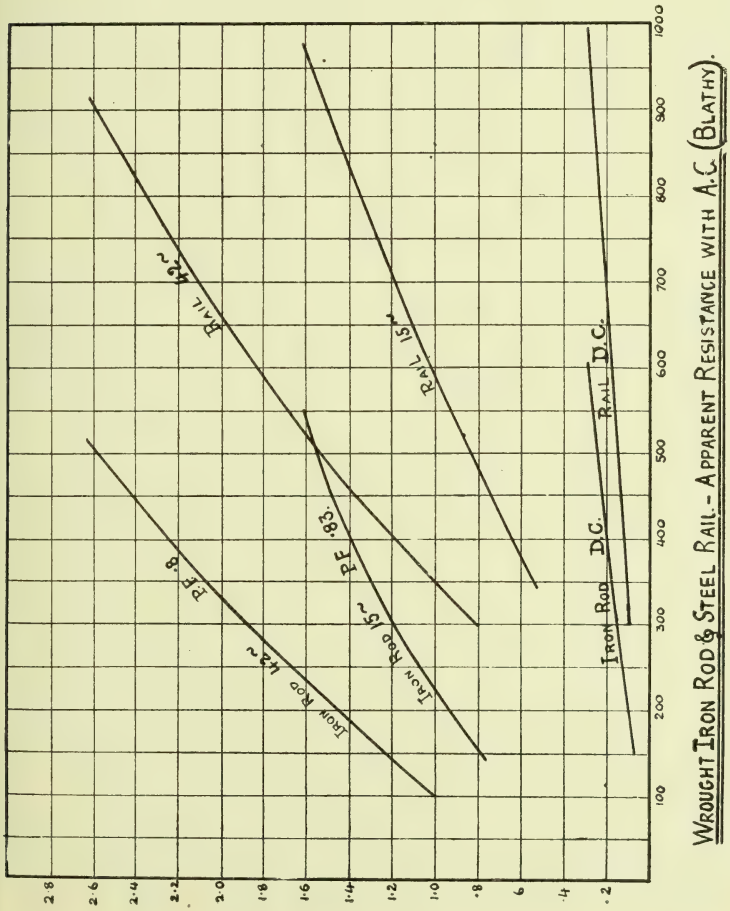


DIAGRAM 6.

an unstated current density is about eight times the ohmic resistance, *i.e.*, about 72 times the resistance of an equal section of copper. Mr. Blathy, of Messrs. Ganz & Co., made some tests on a round rod of iron, and on steel rails, with alternating currents at 15 cycles and 42 cycles per second. The round rod was 1·95 square inches in sectional area, and 16 feet long, and the specific resistance was 7·2 times that of copper. The rail was 6 square inches in sectional area, 23 feet long and weighed 60 pounds to the yard, the specific resistance being 8·87 times that of copper. The curves which are given on Diagram 6, and which are taken from Messrs. Mordey and Jenkin's paper, represents the results obtained.

Mons. Blathy notes that the power factor observed in his tests with the iron rod showed that only 80 or 82 per cent. of the observed drop represents energy actually lost in the rod and probably the same results hold good for the steel rail. With alternating current, however, the rail drop of voltage permissible is not limited in any way, as the electrolytic action need not be considered.

TABLE II.

LOSS OF VOLTAGE IN RAIL RETURN.

Total Current in Two 90-lb. Rails Amperes	Amperes per square inch	Volts per Mile			Yards for 7 Volts		
		Continuous Current	Alternating Current		Continuous Current	Alternating Curre	
			15 ~	42 ~		15 ~	42 ~
1,000	56·5	21	120	210	585	103	59
900	50·8	19	101	176	650	122	70
800	45·2	16	85	147	730	145	84
700	39·5	14	66	112	835	185	110
600	33·9	12	53	87	972	233	141
500	28·2	11	39	67	1,160	318	185
400	22·6	8	28	50	1,460	446	244
300	16·9	6	21	34	1,950	597	358

The Table which is now given, and which is also that used by Messrs. Mordey and Jenkins shows the calculated results that would be obtained by using two 90-pound rails and excluding the effect of

joints altogether. The increased apparent resistance of the track with alternating currents would be a very serious matter were it not for the fact that a so much higher line voltage is possible, and that as the transformer sub-stations require no attendance beyond occasional inspection, and do not represent a high initial capital cost, they can be put very much closer together, and, in consequence, the distance between feeding points would be reduced.

These facts, coupled with the fact that the currents used would be decidedly smaller, would permit of a great deal lower percentage drop of voltage with the same initial capital outlay. It seems probable, however, that as alternating current systems develop the present practice of bonding the steel track and using it as the return conductor may be done away with, and instead an insulated copper conductor earthed at one point and led along the track will be used as the return. For an alternating current system of comparatively high voltage, and certainly anything like a high periodicity, the capital cost of using an insulated copper return conductor will be less than that of going to the expense of bonding all the track, as would otherwise have to be done. The much lower value of the self induction of copper than of iron would enable a comparatively small section conductor to be used.

From the above considerations it is apparent that a low periodicity is of advantage for railway working with the exception of the one point of train lighting. It is improbable, however, that the question of lighting merely will be allowed to interfere permanently, as this could be arranged for quite simply on one or other of the train lighting systems now in existence, and from many points of view it is distinctly advantageous to keep the lighting arrangements entirely independent of the power system in view of the possibility of a breakdown on this latter.

BATTERIES.

As it is apparent that with the direct current motor equipment on a line having vehicles with high accelerations the load variations are bound to to be considerable, a question which has gained some attention of recent years has been the provision of batteries working with reversible boosters, and used to damp out some of the peaks on the generating plant. Automatic reversible boosters working with batteries, either on the Highfield, Thury, or Turnbull and McLeod systems, have been used in a number of tramway generating stations in this country, and where the number of cars running is comparatively small, and the percentage variation of load in consequence con-

siderable, they have given most satisfactory results, and have raised the load factor of the plant running, and reduced the costs per unit generated considerably. It has, therefore, been found desirable in certain cases to use battery systems on some of the electrified lines in this country, and one local case, of course, is that of the Mersey Railway.

In this case the booster group consists of 2,000 ampere reversible shunt boosters, a compound wound exciter, and a 150 H.P. compound driving motor. The booster armature is in series with a battery of 320 cells having 1,000 ampere hours capacity at one hour rating, and capable of giving 2,000 amperes momentary discharge.

On the City and South London Railway, which is the three-wire railway previously referred to, batteries are used in the manner described in the Appendix. It is probable that the use of batteries and reversible boosters at the sub-stations of the Lancashire and Yorkshire Liverpool to Southport railway, would tend very considerably to improve the operation of the rotary converters, which, when this Society went over the line, showed a distinct tendency to sparking with variations of load. This levelling up of the load would also have a very good effect upon the working of the plant in the power station, as it was apparent that the maximum demand peaks on the generators were very steep.

It has been suggested in some cases to put batteries and ordinary feeder boosters between the converter sub-stations on such a line as this, and to use the battery to keep up the line voltage at times when the demand on a section is very great owing to one or more trains accelerating. While this arrangement reduces the cost of feeder cables, it would seem to be bad practice, as it would really be better to have the batteries at the sub-stations themselves, thus evening up the load and keeping the primary alternating current voltage more constant, and to use feeder boosters and additional feeders to keep up the line pressure. A direct current or composite system can use batteries considerably more simply than a plain alternating current system can, but with suitable motor-generator machinery it is possible to use batteries in conjuction with a plain alternating current system, although the number of cases in which this would be good policy are probably limited.

INSULATED RAILS VERSUS OVERHEAD CONDUCTORS.

The author has endeavoured to show in the earlier portion of this paper that if the electrification of anything more than suburban railways is to be undertaken high transmission and supply voltage is

essential, necessitating inevitably the use of a single phase alternating current system. This being admitted, it is obvious that the supply current through an insulated rail, either between the running tracks or in the 6-foot way, is out of the question. It is quite open for a railway engineer to argue that, on account of the physical difficulties in the way of high voltage overhead conductors, they are also impossible in existing main line railways, owing to the awkwardness of finding positions for placing the necessary poles for carrying the conductors when passing over bridges and viaducts, and also because in tunnels the head room is so limited that there is not space for an overhead conductor and the necessary trolley bow. The author fully admits the fairness of these objections, and it is quite apparent that in many cases the cost of the overhead equipment would be far and away greater in converting an existing railway than if the work was being commenced on an altogether new line. Notwithstanding this, however, more difficult engineering problems than the arrangement of an overhead conductor, even for the worst places of the ordinary running track have been overcome, and if, on other grounds, it was decided that the electrification of a main line railway would be desirable, it is not probable that the objections to the overhead conductor would be found insuperable. The Berlin-Zossen high speed railway trials show that it is quite possible to collect a large amount of energy from an overhead conductor with a vehicle running at very high speed, although, of course in that instance, there were no limiting conditions as to the amount of head room available. What seems to the author to be the most difficult part of the problem is the case of the sorting yards and the shunting lines outside large stations, where the complication is bound to be considerable. Live rails in a situation of this kind are, of course, unthinkable on account of the risks which the shunters would run, and it is possible, even if the main lines were electrified, that the shunting would have to be carried out by auxiliary steam locomotives. Upon such a point as this, however, no one except a railway engineer thoroughly acquainted with the practical working of shunting operations could speak decidedly.

RETURN OF ENERGY TO LINE WHEN BRAKING.

On lines having long non-stop runs the question of the return of energy to the line by the train motors when coasting or during retardation is a matter of small importance, but on short lines, where the trains are nearly always accelerating or braking, and where the

length of run at maximum speed is very short, it becomes a problem of very considerable importance, and one to which, up till the present time, little attention has been paid. On the Central London Railway the engineers adopted a simple expedient to prevent the unnecessary expenditure of energy during braking, that is, they arranged that all the stations should be on the top of a slight gradient, so that the train on entering the station stored up energy in itself when mounting the gradient, which was given out when leaving the station again and descending the next incline. This, however, is a very special case and not one which is generally applicable.

It is probably well known to most of those present that during the last year or two a considerable amount of attention has been given on tramway systems to what is known as the Regenerative Control System of Braking. This arrangement, which has been suggested many times, has been revived and developed by Mr. Raworth, who has shown that on a considerable number of tramway tracks, using shunt wound motors and arranging the connections so that when the car is coming down a gradient the motors can return energy to the line, very decided economy of power is possible. Similar arrangements are practicable whereby during braking the motors could return energy to the line, but it is very much simpler to do this with alternating current motors than with direct current, and on a number of alternating current systems with steep gradients this matter has received attention.

A somewhat striking example of the waste of electrical energy which large numbers of accelerations and retardations demand is shown in the case of the Liverpool Overhead Railway, with the new equipment now running on that line. The overhead railway is 6½ miles long, and has seventeen stations, averaging 620 yards apart. The time for the complete journey is 20·4 minutes, the average speed all through being 19 miles an hour. A stop of 11 seconds is allowed for at each station. Diagrams which have been published of trial runs on this line, show that with an acceleration of about 4 feet per second per second, only 21 per cent. of the energy supplied is usefully employed in driving the trains, 50 per cent. of the energy supplied is wasted during the period of braking; about 11 per cent. is lost in the motor, and 18 per cent. in starting resistances and other minor losses. This is a somewhat striking result, and is due to no defect in the apparatus employed, but simply on account of the special conditions which have to be met. It shows also that the overall efficiency of the electrification of short distance lines, where large accelerations and retardations are necessary, is not so great as might be anticipated. On

the Central London Railway previously referred to the amount of energy usefully employed in driving the trains is about 47 per cent., and this better result is accounted for by the switchbacking arrangement of the stations on this line.

FINANCIAL CONSIDERATION.

As has been previously pointed out in this paper, the main question upon which the electrification of other than suburban lines hinges is the question of the financial results obtainable. On a suburban or tube railway, where the cost of the line may amount to from £400,000 to £700,000 per mile, and where the traffic density is enormous, the percentage cost of the electrical equipment is very much smaller than in the case of a main line railway with a capital expenditure of £40,000 to £50,000 per mile. In the case of the short suburban lines, the necessity of the scrapping of the whole or most of the existing vehicles, or the sale or transfer of them for use on other lines or other sections of the same line, is not an extremely important consideration, but with a main line railway it is a very different matter. It is estimated that the value of the locomotives of the London and North Western Railway comes out at about £7,000,000, and if this had to be discarded, either at once or gradually, and equivalent electrical equipment provided, the capital cost to be faced would be very great, amounting to perhaps £12,000,000 to £15,000,000. When in addition to this the capital cost of the main generating stations, the overhead equipment and the transformer sub-stations is considered, the figures which would be arrived at would be very large indeed, and very great economies in operation would be necessary before a Board of Directors would feel justified in commencing the conversion of their lines. The existing steam locomotive is a very efficient machine and has rendered very great services to the community, and notwithstanding the fact that the electrical operation of railways offers many advantages, the author can quite appreciate the attitude of mind of those railway engineers who are of the opinion that except for suburban lines the steam locomotive will remain with us always. Probably for very considerable sections of line they are quite correct, but the likelihood is that within (say) the next ten years, engineers will come to a fairly definite understanding as to what value of traffic per mile of line will justify electrification. For new lines (of which of course in this country we can expect very few) it is exceedingly likely that they will be worked electrically from the outset, as in such cases the necessary arrangements can be made from the beginning.

It would be possible to write a much longer paper than the present one on the financial aspect of the question alone, for it is really the most important one, as in a few years it is certain that the complete practicability from a technical point of view of the electrical operation of main lines will be admitted.

In preparing these somewhat fragmentary and disconnected remarks for this Society the author must apologise for the very large number of things left unsaid, and also for the very large number of points which have not been touched. Upon a subject such as this, papers without end might be written, each dealing with sections of the subject, and it is most difficult to deal more than very briefly with a number of the points which demand consideration.

In closing, it would seem desirable to summarise briefly a few of the more important points.

Firstly, it is exceedingly desirable that if, and when, the electrification of lines other than short local lines, is decided upon, the various Railway Companies should agree as to the main principles which they decide to follow.

Secondly, methods of electrification which have been adopted up to the present for short local lines are quite unsuitable for main line railways on the score of capital cost alone, apart altogether from the vital technical objections which could be raised.

Thirdly, the Board of Trade requirements as to the maximum voltage to be employed, and also a number of other points, require to be modified ; and

Fourthly, the necessity for the use of overhead conductors requires to be faced.

As the number of points of possible disagreement on these subjects is so large, the author trusts that there will be a good discussion, as this will probably afford considerably more information than is to be obtained from the paper.

APPENDICES.

APPENDIX I.

City and South London Railway.

The system of transmission and distribution on this line is an interesting one for several reasons and deserves consideration. The plan adopted might be described as a three-wire 1,000 volt system for the two tracks, with a five-wire system of transmission at distant points at a pressure of 2,000 volts.

In this system two 500 volt dynamos in series at the power house supply current to the conducting or live rail in each of the tunnels. These two live rails form the outers of the 1,000 volt three-wire system. The track or running rails of both tunnels form the earthed middle conductor. Balancers are connected across the system at intervals, and batteries are provided at the power house and two other points on the route.

Generally speaking, the arrangement is simply the Hopkinson three-wire system applied to a railway. For supplying the more remote parts of the line from the power house an interesting method of utilising a higher voltage is used. Two additional 500 volt dynamos are connected in series with the main generators, one on either side, and may be either steam driven or electrically driven by the main dynamos, thus forming motor-generators. With this arrangement there are four 500-volt dynamos in series supplying high tension feeders at a pressure of 2,000 volts. Each pair of feeders is taken to a sub-station containing two dynamos, each dynamo having two 500-volt windings on its armature. Each of these double-wound machines forms a motor-generator. All the four windings are connected with their electromotive forces in series. The middle wire, which in this case is the track, is connected to the middle point of the series, and the two live rails are connected respectively between the first and second and between the third and fourth armature windings. The current in each high tension feeder passes through one winding on its way to the live conducting rail, losing 500 volts, or half its voltage to earth. This winding acts as a motor and causes the second winding

to act as a generator, which produces a current approximately equal to the motor current, also at 500 volts. The two currents in parallel enter the live rail at a pressure of 500 volts from earth. A similar sction takes place at the other machine, thus each machine halves the pressure and doubles the current. As machines used in this way transmit half the energy without transformation and directly convert only the other half, they need be only half the size of ordinary continuous current converters, and their losses are proportionately less. This method may also be applied to any two-wire 500-volt system, giving the advantages of 1,000 volt transmission for feeding distant points, which would be equivalent to one side of the City and South London Railway system, but without balancers.

APPENDIX II.

Cost of Transformer Stations.

In Messrs. Mordey and Jenkin's paper it was estimated that the total costs per K.W. for sub-stations were approximately as follows :—

Alternating Current Transformer Sub-Stations ...	£3	7	0	per K.W.
Rotary Converter Sub-Stations	£12	5	0	"
Motor-Generator Sub-Stations	£15	2	0	"

These prices, which seem to have passed without comment at the time, are now very much on the high side, and the Diagram No. 7 herewith shows very much better what might be regarded as modern prices. Taking a station with about 500 K.W. sets, therefore, we may take it that for a rotary-converter sub-station, including for buildings, the price should be from about £7 5s. to £8 per K.W.; for a synchronous motor sub-station about £8 per K.W. ; and for an induction motor sub-station about £9 per K.W., allowing £2 per K.W. for switch-gear and connections. A plain transformer sub-station with switch-gear and buildings should not cost much above £3 per K.W.

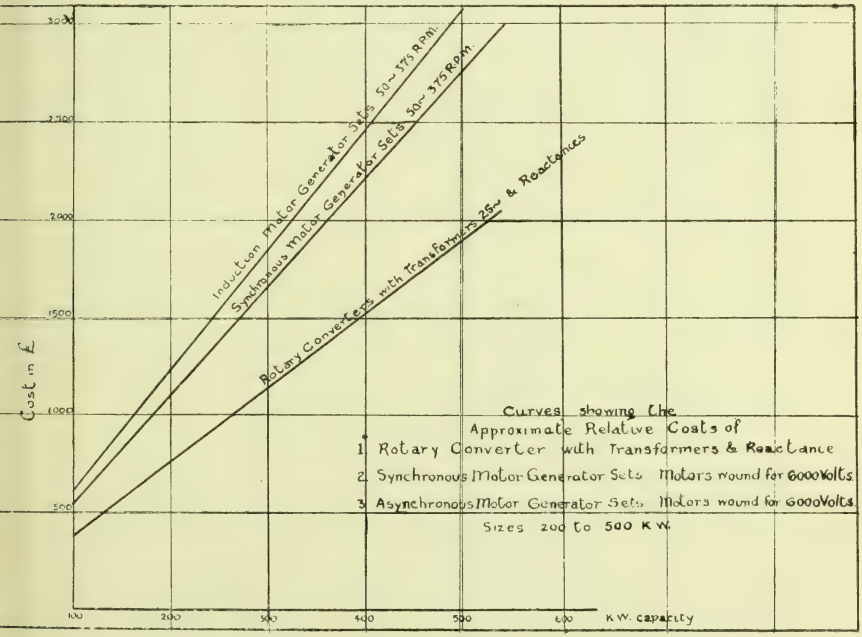


Diagram 7.

APPENDIX III.

Tangential Traction System.

Under this Appendix it is proposed to give a short account of a new and ingenious system of traction, which has been invented by Messrs. Rosenfeld, Zelenay and Dulait, of Charleroi, Belgium. This invention, which appears to have distinct commercial possibilities, is only outlined very briefly in the description given, but the idea is, that the track itself is used to act as one of the constituent parts of the induction motor.

This novel system of electric traction is based upon the direct application of polyphase currents, and its main characteristic lies in the entire absence of any rotating motor on the car, and of any connection between the car and the source of electrical supply. The working principles of the scheme may best be described by referring to the ordinary polyphase induction motor. Here we know a revolving magnetic field is produced through the interaction of the polyphase currents let into the primary element or stator. The speed of this magnetic field is solely dependent on the frequency of the supply and on the number of poles used in the winding of the motor. By means of reaction in the secondary element, a torque is produced which imparts a rotary motion to the latter. The speed of the rotor will differ from that of the revolving field by the slip, which is proportional to the work the motor has to do. Now, if the primary element is developed along a plane, and the secondary element is suspended over it at a suitable distance, the rotary pull will be changed into a rectilinear one; and, based on this principle, the inventors have laid their primary element or stators along the track, while the secondary element—called propellor— is fixed on the car.

To make this scheme commercially useful, it was first of all necessary to avoid the small clearance between stator and rotor, which is essential for obtaining efficient induction motors. This matter has been solved by the use of *polar extensions*, which allow an increase in the air gap without increasing the necessary magnetising current or copper weight of the winding. For instance, to increase the length of air gap in a given motor three times, one has to use an iron surface at the gap which is three times as large. Now, instead

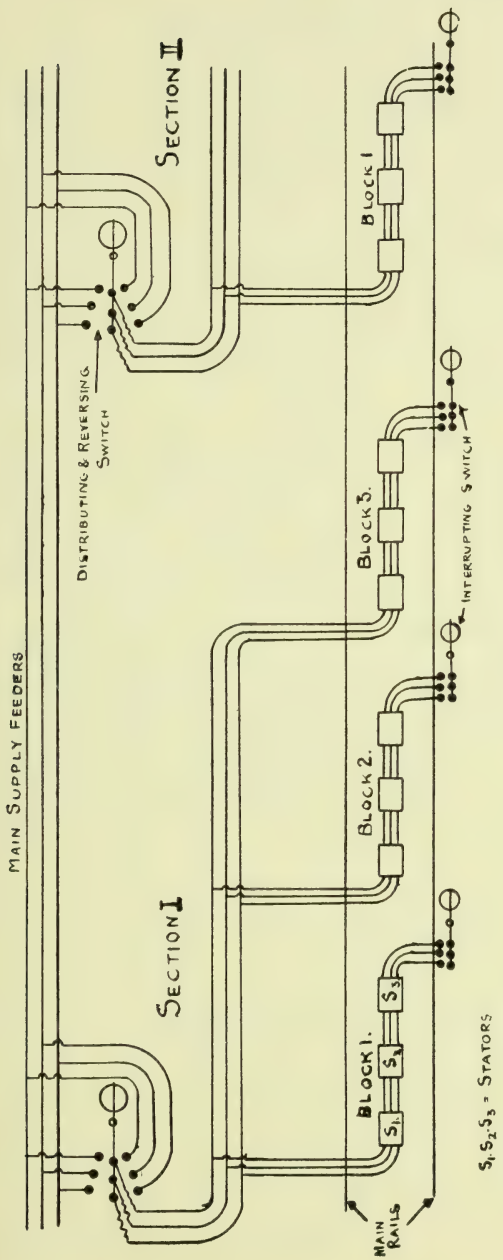


DIAGRAM OF CONNECTIONS FOR TANGENTIAL TRACTION SYSTEM.

DIAGRAM 8.

of enlarging the whole of the core, as would be done in ordinary induction motors, the inventors keep the core and the windings the same, but enlarge the pole face area by means of packets of sheet iron laid transversely, the pole itself being laminated longitudinally.

Now these stators, which are supplied directly with the high tension currents, need not be fixed all along the track, as may be assumed from the explanation of the principles; but in order to supply the normal tractive effort, it will be sufficient to have stators which occupy only a small fraction of the permanent way. The spacing of the stators is determined by the required torque, and by the length of the propellor. For instance, with a car 40 feet long and a stator of 6 feet long, the distance from centre to centre of stators would be about 40 feet on *level track*, while the density of the stators would be increased in the stations to obtain a high rate of acceleration, or on the grades and curves.

This spacing of the stators improves matters as far as capital expenditure goes, but something further had to be done to reduce the excessive cost of working due to the losses which the simultaneous excitation of all the stators would introduce. The inventors therefore divide the whole of the system into sections of suitable length, and these again into blocks, each containing several stators, as shown in the accompanying figure. All the stators of one block are connected in series, and the three ends of the last stator of each block are connected with the contact points of an interrupting switch, while the individual sections are connected by means of distributing and at the same time reversing switches, to the main supply feeders. Both these switches are controlled through small three-phase induction motors.

DISCUSSION.

Mr. OLIVER WINDER said—We have listened to a paper which covers a large amount of ground, some of it that applies to the general question of finance and some to the methods of operation. Some parts of the paper go into technical details that I, for one, cannot follow. Mr. Winder

I want to look at it from the railway and mechanical points of view. Generally speaking, the author has looked upon the matter almost entirely from the point of view of economy of cost of operating the various lines. In suburban work I do not think that is sufficient. Any one going in for electrification work can count upon a very considerable increase of traffic if the scheme is properly laid out, and the line run as it should be. Probably in goods-working no slight increase of efficiency or ease of operation will make much difference to the amount of traffic unless it can be hauled at a lower cost.

The author has, I think, disposed of the various polyphase systems, and the whole matter seems to come down to a question of single-phase or direct current operation; it has struck me that he is perhaps putting rather too favourably before you the question of single-phase operation. We are only on the verge of this particular question, and though we are very willing to see what single-phase traction will do, it is well to remember that very little has been done yet. Moreover, I say to you, there is reason to assume that direct current has by no means been fully worked out.

Certain specific references have been made in the paper to the Lancashire and Yorkshire Railway system between here and Southport, of which I should like to speak. First of all with regard to the matter of rail drops. In using a track return as against a special return, you have the opportunity of using, as we have done, two rails to reinforce the two sets of track rails, making altogether a very large section of steel for the current to return by; the result is that the drop in potential is by no means so large as would be imagined.

The author has also made some remarks with regard to batteries. I am able to say that on this line batteries are being adopted and I think there is no question that batteries can be taken as of considerable advantage. He has rather an ingenious way of introducing the question of batteries with single-phase working. I think if the profit and loss in that section were worked out it would be interesting, as the loss in efficiency would be considerable.

Mr. Winder

He goes on to speak of the loss of energy on the Liverpool Overhead Railway. This loss may be considerable on a line such as that where the stations are about 620 yards apart, and where the starting currents are used over a great portion of the total running, but when you consider lines where the stations are so much further apart, the amount of time during which the resistances are in use, with the consequent loss of efficiency, is of much smaller proportion, and the efficiency of a suburban line generally can be looked upon as a figure many times higher than he has given.

Mr. O'Brien

Mr. H. E. O'Brien said—I would like first to sympathise with the author in the difficulty he must have experienced in getting information for his paper; all the most valuable information on the subject is in the possession of the great electrical manufacturing firms, and with a few Railway Companies in the United States, and this makes the writing of a paper of this particular subject a most difficult task.

I differ with his opinion that an A.C. single-phase system is the most suitable for the electrification of a main line. The word "impossible" is not known to an engineer, but the words "financially impossible," &c., are often before him. The data on the capital cost and on the maintenance and mining costs, and on the likelihood and frequency of interruptions to service, have been arrived at with fair accuracy for electrifications with D.C. motors and D.C. distribution either from sub-stations or direct from the power station, but these data are almost entirely loading for A.C. traction work.

The present field for A.C. traction, either single or multiphase, lies in extensions to existing lines or on new lines with a light but growing traffic.

The first and technical difficulty and a serious difficulty with A.C. traction is the disposition, support and inspection of a high tension trolley wire on a busy line; the experiments made by the Oerlikon Electrical Manufacturing Co., in Switzerland, show this, and they have tried to design and have succeeded in designing a line easy of inspection. Who, however, will remove and replace a broken insulator on a 3,000—6,000 volt line when alive, how long will it take to get the line made dead for the purpose of making the repairs and to what extent will a main line service be affected by such a failure. A railway manager would want a guarantee against claims before he would instal such a system.

A second difficulty arises in connection with the various types of traffic. Certainly no multiple unit system will deal with main line work, and locomotives of large power must be used. Further

difficulties would be met with in the turnover from steam to electrical workings due to the action of steam and smoke from locomotives on the high tension collector lines and in the large loss in the capital standing in the power house and sub-stations and the uneconomical workings of the same during the turnover. Mr. O'Brien

The author shows that for interurban lines the capital cost of the A.C. generation, D.C. distribution system is 25 per cent. higher than the A.C. single-phase system. For an English main line the difference in capital cost would be smaller owing to the recognised unsuitability of the A.C. single-phase system for the local traffic at the large centres of population interspersed along a main line.

It is impossible to avoid some reference to the Liverpool and Southport line. We have there obtained most excellent results with the third rail D.C. system, not only have the engineering results been eminently successful in spite of the widely fluctuating load, but the troubles from the third rail have been nil, with the exception of one or two regrettable accidents to trespassers in the very early stages of the undertaking.

Finally, I would like to comment on one or two of the figures given in the paper.

The figures of £500,000 per mile for the Central London Railways covers the cost of the whole line and has no bearing whatsoever on the subject under discussion. The cost of A.C. generation, D.C. distribution, electrification of a main line may be taken as roughly, £8,000 to £10,000 per mile, including rolling stock, &c. The figures on the acceleration on the Liverpool Overhead are misleading, as the acceleration of 3 feet per second is only momentary.

To conclude, I would say, that though the opinion may be partly due to the prejudices due to an upbringing on a railway among locomotives, I think that the efficiency of the locomotive is so high for long distance work that it will not be displaced in that field for many years by any electric traction system, though there can be no doubt of the greater suitability of the electric multiple unit train in the field of heavy surburban traction. The question of the system best adapted to branch lines seems still an open one, and only experience will show whether petrol, steam, or single-phase, is the best. Finally, the subject of electric traction is such a large one, and can only be so lightly touched in a few words, that one must apologise for venturing to discuss it at all on such an occasion as this.

The Discussion was adjourned to the next Meeting.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

ELEVENTH MEETING—5TH APRIL, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

Adjourned Discussion upon Mr. H. W. WILSON's Paper, entitled—

"ELECTRIFICATION OF RAILWAYS,"

which was read at the Meeting on the 22nd March, 1905.

Mr. Salter

Mr. J. R. SALTER said—It seems to me that we engineers are as much controlled by the dictates of fashion as ladies are. We are first enamoured with high-speed engines, and then with American low-speed engines, and now there is nothing which appeals to us more strongly than the Turbine. It is just the same with the systems of generation and distribution. In the early days single-phase alternating current was the only system adopted. We then got to continuous currents with batteries, and with the advent of traction and power supply we were persuaded that the three-phase system was the best, and we now return to the single-phase system as the only practicable system of electrifying our railways. I think that we are carried away by the prevailing fashion and are rather prone to overlook the advantages of systems which we have previously used, to emphasise the disadvantages whilst appreciating the advantages of the new system and overlooking the disadvantages probably through lack of experience.

As I have indicated in my opening remarks, the question of capital cost involved is the one which will probably determine the choice of system to be adopted, and the question again resolves itself into one as to whether the larger capital cost of a particular system is more justified by the reduced working expenses as compared with another

system. Now the difference in capital cost between the continuous current system and the single-phase alternating system, according to the table which the author gives, is only some £395 per mile; the interest upon this is some £15 or £20 per mile per year, and it is to effect this small annual saving in interest upon capital that has determined the choice of the single-phase system, which requires the use of overhead wires along the railway track, from which the current is collected for propelling the train. In the first place, I do not think the comparison of cost is strictly speaking a proper one: whilst we are told that in the electrification of railways we must not assume that the problem will be dealt with as a glorified tramway system, it seems to me that in making the comparative cost of electrification, the basis of the comparison is made upon the supposition that the continuous current method which is adopted is really that of a glorified tramway undertaking. It seems to me that there is another method of employing the direct current system, which is well suited to railway working, and which has already been very successfully applied upon the City and South London Railway, the system being the continuous current three-wire system. If such a system were employed at a pressure of 1,300 volts between the outers, it would considerably affect the capital cost of the continuous current system, and would probably show an advantage in favour of the continuous current system. By doubling the voltage of transmission in this way, the distance of transmission would immediately be quadrupled with the same percentage loss, and inasmuch as the current in the running rails which would be used as the middle wire would only be that due to the unbalanced current on the two sides of the system, you would overcome a great deal of the difficulty in connection with using the earth as a return. As against this, with the system which the author advocates, you have a very large inductive drop in the rails necessitating an increased consumption of energy, and you have the heavy maintenance charges which must of necessity arise with overhead wires. The cost of maintenance of overhead wires upon a tramway system is a very heavy item, not so much by reason of the repairs which are necessary, but by reason of the fact that it is necessary to always keep available for repairs a staff of men with Tower Wagons who are but little employed during the greater part of the time. With such a voltage as 3,000, it is evident that the insulation of the overhead line must be well maintained, and frequent inspection will be necessitated to provide against mechanical defects in the supports. Even assuming then that the saving in capital cost

Mr. Salter

Mr. Salter in favour of the single-phase high tension system is correct, these difficulties have to be faced, and simply for the purpose of effecting an annual saving of £20 per mile per annum; but if the system which I have referred to, viz., three-wire continuous current system were employed, even this annual saving will not be effected, and it seems to me that the system is admirably suited to the electrification of main railways, as there will not be present the troubles from acceleration and retardation which are present upon local lines. With the electrification of railways, it appears to me that it will be found expedient to run a very much smaller train unit and to give a frequent service. Of course, the present large train units have been more or less adopted to reduce the locomotive costs, and with electrification, the question of locomotive costs disappear. I look forward to the time when it will be possible to have a ten minutes service between Liverpool and London, for the reasons already stated; such a service would undoubtedly considerably increase the traffic.

With the adoption of the continuous current system, the third rail could be used, and the heavy maintenance charges of overhead wires obviated, and in connection with the third rail, there is one point which I should like to call attention to, that is, in regard to the public safety. We have all heard a good deal lately about the dangers of live rails, and it is somewhat surprising to me that the railways which have adopted the third rail system have not introduced the surface contact or sectional rail system. This system has already been applied to tramways with considerable success notwithstanding the fact that the ordinary vehicular and pedestrian traffic has to be protected, and the current collected from small buttons in the road. The conditions of railway working are much more suitable to the adoption of this system than are those of tramways. Instead of it being necessary to have small buttons or studs, from which the current has to be collected, a considerable length of rail could be used with a small break between the sections, and the difficulties of maintaining the tramway paving so as to retain its relative position to the studs in the road are not present. With this system the third rail would only be alive whilst the train was actually over it, and, therefore, all danger to life would be removed.

I will only now refer to the question of the employment of batteries. Here, again, I think it really comes to a question of fashion as to whether they should be adopted or not. A battery involves a considerable outlay in first cost, and a considerable continuing cost, whilst the losses amount to about 20 per cent., but it is not at all

apparent to me how the author proposes to utilise batteries in connection with a single-phase alternating current system of generation and distribution. Mr. Salter

Mr. W. D. KIRKPATRICK said—It is with considerable hesitation that I attempt to discuss the author's valuable paper on Railway Electrification. There are, however, one or two points I should like to raise. On page 182 the author mentions the third and fourth rail equipment as possible methods of supplying the energy to the motors. It has occurred to me, that if the "live" rail—to use a well-known word for the positive rail—was split up into sections, (say) 1 foot long, placed on every alternate or every second sleeper of the existing track, the danger of it to persons attempting to cross the track would be reduced to a minimum The collecting shoes, of course, would require to be lengthened so that they would come in contact with two or more. These studs would be connected underground by a copper cable in the usual way, and could be made of non-magnetic metal for alternate current working. Regarding the author's remarks on page 185, third paragraph, it is only necessary to inspect the track of the Liverpool Overhead Railway, to see what will happen if Railway Companies do not come to some common arrangement as to how the work is to be carried out. In this case there are already two live rails to each track. What would be the acceleration possible by the arrangement by Mr. Ward Leonard described on page 192. Mr. Kirkpatrick

In conclusion, I should like to ask the author if he has any data of the wear and tear of the track of our electric railway as against steam. That is, does the more even turning moment and multiplication of wheels tend to save the rails and sleepers or otherwise?

Mr. T. L. MILLER said—I did not come here to-night with the intention of joining in the discussion as I can hardly be expected to criticise Mr. Wilson's paper, and it would, I think, be out of place for me to eulogise it. Mr. Miller

There were, however, one or two remarks made at the last meeting by Mr. O'Brien, which I think I might refer to. In his remarks Mr. O'Brien drew a very hopeless picture of the overhead conductor as applied to railway electrification, painting very vividly the terrible dangers the passengers would be subjected to in the event of the overhead conductor coming down. From the tenor of his remarks I do not think Mr. O'Brien can have followed the recent developments of the alternating current systems applied to traction on either the Continent or in America. It would appear from his remarks that he considered the work would be carried out on the lines of the present

Mr. Miller tramway systems where the wire is supported at intervals of about 40 yards. This is not the idea of the construction required for a railway system, for the details of the arrangement will have to be something very much more substantial than anything to be found in ordinary tramway work. The construction adopted in the States and on one or two railways where overhead conductors are used, or where designs for same have been got out, is to carry one or two steel cables above the track and to suspend the conductor from such cables at every 10 or 15 feet. It will be seen at once from this construction that should a break occur in the conductor the greatest length which can possibly fall is the distance between two supports, so that there is very little likelihood of a long length of conductor falling down; and, further, owing to the conductors being supported at such short intervals the stress in them is much less than that of the tramway conductor, and there is consequently much less probability of their breaking.

Assuming, however, that the overhead construction is not suitable for railway working—an assumption I am not prepared to concede—I do not think that it necessarily puts the single-phase system out of the running, as it is quite possible with the low periodicity which is proposed, to use the third rail alternating current system fed at a pressure of (say) 650 volts from transformer sub-stations placed along the line of route. If this system be adopted we get rid of all the troubles and expenses of the moving machinery in the sub-stations and the consequent attendance required therein, while at the same time the new single-phase induction motor could be made to work both on the low periodicity third rail system and on the direct current third rail system which is being used in a number of undertakings, of which the Lancashire and Yorkshire Railway Company's system may be taken as an example. Of course the efficiency of the motor, if constructed on the alternating current system, would be somewhat low when running on the direct current system, but the principle fact to bear in mind is that with such an arrangement the one type motor can be run on either system.

Referring now to main line working: I think there is too great a distinction made between the main line and suburban traffic, as the main line system of necessity runs through large towns, all of which have their suburban traffic extending a considerable distance beyond the centre of the town, and which tends to shorten the distance required to be dealt with by what is usually known as the main line traffic. As an example I would take the case of the running between Liverpool and Manchester, where the suburbs round each

town extend for a very considerable distance. Assuming that the suburban lines of both these large centres of population are electrified, then the distance required to be dealt with in order to electrify the lines between Liverpool and Manchester would be a very small proportion indeed of the total length. Mr. Miller

What applies to Liverpool and Manchester would apply in a very great measure to the main line traffic between (say) Liverpool and London, where the railway runs through large centres of population, and where if the suburban lines in connection therewith were electrified the total length of the main line to be dealt with would be very materially reduced. Of course the point of this is that when once we have the suburban lines electrified we have dealt with the greater portion of the problem.

Mr. Salter, in his remarks to-night, has referred to the question of batteries, and I must say that I do not agree with the views he has expressed with reference thereto.

According to Mr. Salter batteries are a very good thing to do without and should be done without on all occasions. Now I cordially agree with Mr. Salter that, as a general rule, batteries are a good thing to do without, but I am not in agreement with him in his general condemnation of them, as I know of very many instances where the use of batteries tends to very greatly decrease the cost of working. At the present time we have a couple of tramway systems working with batteries, and in both cases the use of the batteries with reversible boosters has resulted in a very considerable economy. In both these cases the total number of cars on the system will not exceed 40, and under these conditions I think the use of batteries and reversible boosters gives extremely good results. Where you come to large city systems, such as Liverpool or Manchester, then the advantages of a battery are by no means so apparent, as the large number of cars tends to level up the load on the generators to such an extent that a battery is really not required, but on small systems with infrequent services, and on lines such as the Lancashire and Yorkshire Railway where the demand during acceleration is extremely heavy, then the battery is of extreme importance, not only as regards economy but also in getting rid of other troubles in the engine house which are inseparable to a system where the demands vary so largely as they do on the systems I have referred to.

Mr. Salter suggests, as an ideal system of railway working, the use of the three-wire system. This has been used in the case of the Central London Railway and, according to Mr. McMahon, has given

Mr. Miller extremely good results, but the conditions of working in the case of the Central London Railway are altogether different to those met with in railway working where the service is much less frequent and where the difficulties of balancing are much more serious than those experienced on the Central London Railway, where a constant stream of trains at very short time intervals is passing over the system.

Referring again to the question of batteries, Mr. Salter stated that the cost of batteries was very high indeed. He is correct here when dealing with long hour discharge, but with the rating usually adopted for tramway batteries with reversible boosters, the cost of the battery and booster is, if anything, less than that of the generating plant.

Mr. Salter has further referred to the question of fashion. Well perhaps fashion had something to do with the use of single-phase alternating current supply in the early days of electric lighting, but at the same time I think it will be conceded by everyone that had we in the early days of electricity supply had a satisfactory single-phase alternating current motor, the great popularity which the single-phase alternating current system of supply had would have been maintained. The reason why this system went out of vogue was largely due to the fact that a satisfactory single-phase alternating current motor could not be obtained. At the present time single-phase alternating current motors can be obtained which compare very favourably with the direct current motor, and if the progress in this direction can only be maintained I feel confident that the single-phase system will again be as extensively used as it was in the past, as the areas over which we are distributing electrical energy are very much larger than anything attempted in the early days of electricity supply, and the adoption of a satisfactory single-phase system would greatly simplify the question of supply, as in place of the existing sub-stations containing rotary converting apparatus, with its consequent attention, we would be able to use sub-stations with static transformers, with a considerable gain in both maintenance and efficiency.

With reference to the tangential system referred to in Appendix III of the paper: I understand that this system has, up to the present, only been tried on a very small scale, but it appears to have in it the elements of success. There are of course considerable difficulties to be overcome yet, but if the cost of the system can be brought within reasonable figures and a satisfactory efficiency shown, it will, I think, have an extended application, as it will get over the troubles which the railway men object to in the overhead system, and also in connection with the live third rail.

Mr. H. W. Wilson, in reply, said—I must thank those gentlemen who have taken part in the discussion, but I regret that there were not more people prepared to disagree with me, because I have raised many controversial points in the hope that much enlightenment would result from their criticisms. Mr. Wilson

Several people have disagreed with me, but unfortunately they have mostly disagreed about the same things, and I cannot say that they have convinced me that I am wrong, though, of course, I quite appreciate the points raised.

Mr. Salter referred to the financial question, and said he did not agree with me that the question of capital expenditure per mile of line was an important consideration, but that the benefit which was going to be derived from the extra expenditure was the important factor. I entirely agree with this, and I have said so in the paper twice. Mr. Salter says that I state that on tube railways and railways of that description, the expenditure comes out to £500,000 per mile, and on main line railways £45,300, but that this does not matter greatly as it is the increase of revenue the extra expenditure provides that is the controlling factor, and not the proportion such expenditure bears to the whole.

Now what I wished to express is this. If you have a line where your expenditure in any case is going to be £500,000 per mile, the comparatively small percentage increase of cost of electrification is much more likely to be justified by the improvement in the service, than in the case of a line where the percentage increase is so large that the improvement in net revenue would have to be enormous to maintain the line's ordinary dividend.

The percentage of increased benefit on main line railways has to be greater than on suburban railways in order to justify expense.

Personally, I have very grave doubts about the practicability of the electrification of main line railways from a financial point of view, and I certainly feel that any Board of Directors will require convincing emphatically that they are going to gain something very substantial before they are justified in starting a scheme of this kind. In speaking of main line railways, of course, I do not altogether mean railways between Liverpool and Manchester and such like centres ; these may be looked upon as semi-suburban railways, but I am speaking of a line of (say) upwards of 100 miles in length between the termini. In cases like that, the question of finance is going to be a very important one.

Well now, to begin at the beginning of the discussion ; at the last

Mr. Wilson meeting, Mr. Winder stated that on suburban lines the cost of operation per train or ton mile is not very important, but that rapidity of service is.

He said that on main line railways the cost per ton mile of moving your goods is the important factor. Well that is perfectly true within limits. On your main line railway the cost per ton mile is the factor that is going to influence the results from a dividend point of view, and on suburban lines it seems to me that unless there is going to be some advantage financially, the electrification of the line is hardly justified, and I should be pleased if Mr. Winder could make his point a little clearer. I take it that the Lancashire and Yorkshire Railway Company were satisfied that they were going to move passengers at no greater cost per passenger electrically than with the steam locomotives.

Now Mr. Winder also says that the single-phase system is in its infancy and has not worked out what it is going to do. That is a style of argument which I have heard about other things, but if we are to always work on that basis we shall not get much further. If single-phase traction is at all satisfactory it will, on his own admission, be considered better than direct current, and whilst I appreciate the advantages of the direct current system, it is not to my mind a suitable system for main line railways.

Then Mr. Winder made a point that the loss of efficiency on an ordinary surburban railway is not going to be anything like as great as on the Overhead Railway where stops are so frequent. I might mention that the figures about the acceleration and retardation on the Liverpool Overhead Railway are taken from published results of tests. Now, of course, it is evident that the Liverpool Overhead Railway represents the worst condition of things you can possibly get, and it must be admitted that on an ordinary railway the results would not be quite so bad.

Nevertheless with the acceleration and retardation which you get on a suburban line, the loss of energy is going to be very great indeed, and even if you take the case of the Central London Railway with its 53 per cent., it is a very serious amount, and I consider with a single phase arrangement you could get a distinct improvement.

Mr. O'Brien stated that the overhead system on a railway was unthinkable owing to the danger of breakdown. My view is that because the Lancashire and Yorkshire Railway Company have got a live rail system they feel, to a certain extent, bound to defend it. I do not think, personally, that many railways would seriously

contemplate putting down a continuous live rail in the future, my opinion being based on the fact that with the voltage it is necessary to employ, any live conductor on the ground level will be impossible. Mr. Wilson

Mr. O'Brien is of the opinion that the breakdowns on an overhead system are going to be as bad as on the live rail system, and, as far as that is concerned, I regret I cannot agree with him.

Mr. O'Brien also made a somewhat extraordinary statement. He said that the variation of load was not of very much importance. That depends entirely upon what you consider a matter of small importance. If the variation of load that the Lancashire and Yorkshire Railway Company are getting on their Southport line is of small importance, why should they put in batteries? And when this Society went over that system some time ago, I was interested to observe the variation in load on the main generators was as much as 1,000 K.W. The effect on the engines was very perceptible, and I do not think it was good for them. I do not think Mr. O'Brien could seriously mean that a variation of load of this kind is a matter of small importance. It would certainly appear to me to be going to shorten the life of the engines very considerably, and certainly it is most desirable from the point of view of coal consumption, that they should get the load approximately constant.

He also said we should have three-phase distribution on lines where the stops are a considerable distance apart, and as the number of sub-stations would be reduced, the amount of attention required would also be reduced, and the cost per mile would not be so excessive.

His argument is sound within limits, but you have times when the load per mile in a given section goes up considerably above the average, and you require to have sub-stations large enough to deal with the maximum demand.

Mr. Salter, apart from the question of capital cost, to which I have referred, disagrees with me principally as regards the method of distribution, and he considers that the method of distribution as used on the City and South London Railway is the most satisfactory. Now Mr. Miller has pointed out already that on a main line railway the probabilities are that between any two feeding points it will be impossible to balance the load, and that to my mind is the main objection to the three-wire system on the main lines. The system adopted on the City and South London Railway is interesting and has been on the whole satisfactory, but if it is as satisfactory as Mr. Salter seems to infer, why has it not been adopted on any other lines?

Mr. Wilson

Mr. Salter also criticised my figures, and said that all the saving shown on the single-phase system was £395 per mile, which is true, but he did not also say that this was only meant as an illustration, and that the saving was only £395 in a particular case, but that it was 25 per cent. of the total cost, and on a main line railway it would be a considerably greater amount per mile than £395. 25 per cent. on the cost of electrifying a complete railway is going to mean a large sum of money.

Then Mr. Salter said that large units were only used on account of locomotive costs. That is, as far as passengers are concerned, unquestionably true, but I doubt whether it is so far as goods trains are concerned. If a railway line carrying a heavy goods traffic is to deal satisfactorily with it, I do not see how they are going to reduce the weight per train much below 800 tons.

Mr. Salter then proceeded to condemn batteries wholesale. I quite agree with Mr. Salter that batteries are liable to give trouble, but at times they are a very great convenience.

Mr. Salter suggests that a modification of the system, which is being used for colliery winding, should be adopted in railway power houses. I believe that one line is thinking of experimenting with this system, but I do not know how it is going to be worked out.

Mr. Miller made some remarks answering, to a certain extent, what Mr. O'Brien said. He pointed out that Mr. O'Brien in condemning the overhead system, did not appear to have considered that the arrangement used in the States might be adopted here.

Mr. Miller then said that single-phase is not limited to overhead conductors but might be used on the third-rail system. Well, there again you have to consider the question of voltages. If you are not going to use a high voltage on your third-rail system, I think it would be distinctly undesirable.

Mr. Kirkpatrick suggests putting the third-rail system in sections. That is all right, but it would probably be better to use one of the practical surface contact systems.

As regards the question of wear on the rails, there is no data at present available, but it seems likely that owing to the larger number of driving wheels the wear on the rails would be somewhat smaller than with the steam locomotive.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

ANNUAL GENERAL MEETING—26TH APRIL, 1905.

FRANK E. PRIEST, M. Inst. C.E.,

PRESIDENT, IN THE CHAIR.

The following gentleman was duly elected to the Society, viz. :—Mr. H. JACKSON TIPPET, as an *Associate Member*.

THE EVOLUTION OF HARBOUR ENGINEERING.

BY A. F. FOWLER, M. Inst. C.E., M.I. Mech. E.

WHEN the shipping of the world was represented by rafts and canoes, harbour works were not necessary, and at a later period it is questionable whether the earlier Phœnicians and Egyptians did more than construct primitive quays for the accommodation of their light draught galleys. Considerably prior to the destroying of Tyre by Alexander the Great, some 350 years before the Christian era—indeed as far back as three thousand years B.C., there were extensive quays, arsenals and warehouses at that place; the same remarks apply to Rhodes, Salamis, Syracuse, and to Carthage somewhat later. Two hundred years B.C. the two first kings of the Ptolemy dynasty finished important works at Alexandria started by Alexander the Great, which included a mole, floating basin, a canal to Lake Mereotis and the famous lighthouse "Pharos."* The Roman Emperors, notably Trajan, constructed harbours at many places on the Italian coast, including Ancona, Terracina, Civita Vecchia and other places. After the fall of the Roman Emperor the predominant sea power was Scandinavian, and owing to the natural facilities which the coasts of Denmark and Norway offer, it can be understood that constructive works need only have been of limited extent.

* Ency. Britt., Vol. 1, page 94.

There appears to have been little development until the 14th century, when the Knights of St. John carried out small works in various parts of the Mediterranean, including the existing moles at Rhodes.

The above works, although of small size, must have been constructed under difficulty owing to want of plant, therefore, naturally advantageous positions were selected which only required protection by means of breakwaters and not deepening.

In the 16th century there was considerable activity in connection with the Royal Navy. King Henry VII founded Portsmouth Dockyard; Henry VIII, Woolwich and Deptford; and Queen Elizabeth, Chatham. The efficiency of the Navy and Dockyards continued with one short lapse—during the Revolution until the Restoration—when according to Macaulay's "History of England," a member of the French Admiralty was sent over by Louis XIV to inspect the dockyards and report, which he did to the effect that everything was in disorder and miserable condition, that the superiority of the French Marine was acknowledged with shame and envy at Whitehall, and that the state of our shipping and dockyards was of itself a sufficient guarantee that we should not meddle in the disputes of Europe. This was in 1686. At that time the mercantile marine was mainly represented by the East India Company, which Company in 1609 constructed their dockyard at Deptford, on the site now occupied by the Surrey Commercial Docks.

After the 16th century there is nothing of interest to record until the end of the 17th century, when the development of trade brought into requisition the genius of Smeaton, Brindley, the elder Rennie and Telford. Brindley had little to do with harbour work proper, but Smeaton and Rennie carried out many breakwaters notable at that date.

Remarking on ancient works and the class of vessels they had to accommodate, it is doubtful what the draught of ancient ships was. There is an interesting work by Mr. Cecil Torr, published by the Cambridge University Press, which describes in detail the structure of the Roman and Grecian Men of War and Merchant vessels, but does not in any case give the draught. In describing the ancient docks at Zea, in the Grecian Archipelago, he states that they were 19 feet 5 inches in width and 144 feet in length, and later he states that "the "tonnage of ancient ships cannot safely be deduced from their "dimensions, as so little is known about their form; generally, however, "the largest ships would carry about 250 tons." In describing the

dimensions of one of the greatest merchant ships carrying corn from Egypt to Italy about 150 A.D., Mr. Torr states, "according to "Lucian, her length was 180 feet, while her breadth was slightly "more than a fourth of her length, and her depth was 43½ feet "reckoning from the upper deck to the bottom of the hold." This vessel evidently could not have entered the docks at Zea, as she must have been about 18 feet draught, and it would seem that most of the ancient dock works were laid out more for the accommodation of the three or four-banked rowing ships used in naval warfare than for the merchantmen of larger size. The warships, in all probability, were not of greater draught than 9 to 10 feet, although Sir John Rennie, in his biography, mentions that the harbour of Civita Vecchia remains serviceable at the present day for vessels drawing 20 feet of water.

The most important part of Phœnician and Roman Harbour Works was the formation of breakwaters. In remarking upon that at Ancona, Sir John Rennie states that the base was formed by large stones thrown down loose and left to consolidate by the action of the sea. This formation was brought up to low-water level and the superstructure was formed of masonry of squared stone and pozzolana. The inside wall was formed by first placing a close framework of timber in front and then a mass of pozzolana, lime, and small rubble was filled in between the boards and the rubble base. When sufficiently solid, the boards were removed and transferred to another section. It will be seen that this practice is almost identical with modern practice to within the last 50 years.

As an instance, the author would refer to the old north pier at Aberdeen, which was started by Smeaton in 1770, and extended by Telford in 1829. It was constructed on a foundation of rubble stone about 75 feet in width, raised to the level of low water, from this level up to about 6 feet above high water, or a distance of 20 feet above low water; masonry walls were built on each side of the mound, having a radius of 33½ feet, so that at the top of the walls there was a distance of 22 feet, the space between the walls was filled in with loose rubble, the platform on the top was formed by blocks 18 inches in thickness, and on the exposed side there was the usual parapet, about 6 feet in height and width.

The description of the old pier at Aberdeen may be applied generally to most of the breakwaters carried out by Smeaton, Rennie, Telford and Leslie and Stevenson, although some, such as Banff and Arbroath, the sea side was built to a slope of from 2½ to 3 to 1. As to cost,

Mr. J. Rennie, in reporting on a proposed breakwater at Port Nessock (about eight miles north of the Mull of Galloway) estimates the rubble free stone for facing masonry at 13s. per cubic yard and the ashlar in parapet at 2s. per cubic foot. For information as to construction of breakwaters between 1770 and 1840 the author has referred to the Royal Commission Report on Tidal Harbours, 1847.

It is to be noted that in very few cases were these breakwaters founded in more than 20 feet at low water, this does not refer of course to the well known case of Plymouth breakwater. There is no doubt that most of the work would be done by hand cranes of from 3 to 5 tons capacity. When it became necessary to create harbours of refuge for large mercantile vessels, more ambitious structures had to be undertaken, and plant specially designed for dealing with large blocks of concrete or masonry had to be designed. Instances of works carried out by private enterprise for purely mercantile shipping are found in the large works constructed at the mouths of the Tyne, Wear and Tees.

The author was engaged on the latter during the term of his pupilage, under his father, the late Mr. John Fowler, M. Inst. C.E., of Stockton-on-Tees. An account of this work is given in the Minutes of Proceedings of the Institution of Civil Engineers.* This breakwater was founded in as much as 50 feet depth of water O.S.T. In general construction it is similar to the old Aberdeen Piers referred to, save that concrete *in situ* was used instead of masonry, and blast furnace slag in place of rubble. The effect of the sea was to spread the slag base over a very wide area, which would indicate that this method is not desirable in a confined space subject to heavy sea, outside the Tees estuary the spread was not of importance. Serious damage occurred at the outer end owing to the slag apron being washed away and the concrete undermined. Had the upper portion of the work been formed of concrete blocks, probably a great portion of the abandoned wall could have been saved.

An instance of a recently completed breakwater is Roker Pier, at the North side of Sunderland Harbour, and through the kindness of the Mr. H. H. Wake, the author is enabled to give the following description :—

The total length of the Roker pier is 2800 feet, 2340 of the shore portion being 35 feet wide ; the seaward portion for 460 feet is 41 feet wide, and the face walls of the pier are battered 1 in 10.

The structure below low water and up to $2\frac{1}{2}$ feet above low water is

* Vol. XC., page 344.

formed of 50 and 115 tons bags of concrete (4 of cement to 1 of sand) deposited in a plastic state on the rock. A twin-screw bag barge vessel, specially designed by Mr. Wake, was used for this purpose, with a large and a small box, with half falling doors in the bottom, slung in the well suspended from hydraulic cylinders; and when deep water was reached this vessel was lengthened for two large boxes of 116 tons. The boxes were first lined with the bags made of jute sacking as the vessel lay under the spouts of the concrete mixing house in the river; when filled they were laced up, and the barge steamed to sea, and was moored over the site where the bag is required; the box was then lowered through the water as near the place of deposit as possible, the doors released and the bag deposited. On the site of the sea end of the pier, there was a deposit of sand on the rock of varying depths up to 17 feet, and this was removed by a sand-pump dredger before depositing the bags.

The superstructure was built in lengths of 42 feet 7 inches of granite-faced concrete blocks, varying in weight from 43 to 54 tons, the end of each length having a crosswall of concrete blocks, and the hearting was filled in with concrete. A subway, formed in the hearting of the pier for its full length, affords a means of access to the lighthouse in stormy weather. The hydraulic radial crane, designed by Mr. Wake, and as used for the block setting, is capable of setting a block, weighing 60 tons, 60 feet in advance of its leading wheel.

The roundhead, formed of an iron caisson, 100 feet long, 69 feet wide and 32 feet, was set on a specially prepared foundation of concrete bags levelled to 24 feet below low water. The caisson was floated out with a draft of 22 feet containing 3500 tons of concrete, sunk on to its site, and filled with concrete *en masse*; block setting was then started, and the roundhead completed. The total weight of the roundhead is 23,000 tons.

The lighthouse is built in bands of red and grey granite, backed with concrete, the floors and stairs are also of concrete, and the light has a focal plane 83½ feet above high water.

The equipment of the lighthouse consists of a third order, quick single flashing dioptric light, flashing 0·1 second and eclipsed 4·9 seconds in every five seconds. The siren fog signal gives a blast of two seconds duration in every 20 seconds. Two gas engines of seven nominal horse power, with air compressors, deliver 25 cubic feet of compressed air per minute, at a pressure of 25 pounds per square inch, into an air receiver in the basement, from which it is conveyed to the sounding receiver on the third floor. The siren, with an automatic

sounding valve in a chest of cast iron on the parapet, has a gunmetal valve and seat with rubber diaphragm, the admission of air being regulated by clockwork, and is self sounding, the clock being driven by falling weights, and the motor is driven by air from the sounding receiver.

The illuminant was gas, but being at the end of a long main supply and gas engines being used, the pressure was intermittent. The gas burner was of 300 candle power, with an effective flash of 40,000 candle power; but as an improvement on the gas light, the Chance petroleum incandescent vapour apparatus is now used, the oil burner giving 1200 candle power with an effective flash of 150,000 candle power.

A similar method of construction to that of Roker was adopted by the late Mr. P. J. Messent at Tynemouth and North Shields. At the Tynemouth Pier trouble arose some years ago owing to the foundations not being carried low enough to resist the action of the sea. This pier is now being repaired under the direction of Sir John Barry and N. J. Matthews, MM. Inst. C.E.

Many of the breakwaters constructed in the early part of the 19th century had their sea faces from above high-water level to foundation level constructed practically in a continuous curve of about 33 to 1, amongst them being Banff—designed by Telford, and Arbroath by Leslie. During the sittings of the Royal Commission on Harbours of Refuge in 1858, evidence was given as to the relative advantages of vertical or nearly vertical faces, as compared with curved and flat battered faces. Mr. E. K. Calver, in reporting on Wick Harbour, strongly favoured the curved face as not likely to cause so much broken sea, and therefore not so dangerous for small vessels and boats. In modern practice the vertical face is adopted to the exclusion of the slope, and on plan straight lines, or a series of straight lines, instead of the curved moles favoured by the ancients. Heysham Harbour is, however, an exception.

The difference of principle in the construction of the piers at Newcastle, Sunderland, Gibraltar, &c., as compared with the new Dover and Folkestone breakwaters, is that in the first case radial cranes or Titans were used, the radius being sufficient to found the pier ahead of the crane, the superstructure afterwards being brought up to platform level and the crane advanced for another length. At Dover an elaborate temporary gantry is constructed, embracing the full width of the breakwaters, a system of Goliaths traverses this gantry, which are used in the working of the excavating grabs,

diving bells and block setting. The Titan method of construction has been more generally adopted than the gantry method in use at Dover and Folkestone, and is more economical, but the gantry method gives the advantage of greater and therefore safer control over the diving bell and block setting operations. In concluding these remarks upon breakwaters the author would draw attention to the fact that mechanical science, in placing at the disposal of the civil engineer the powerful plant briefly referred to, has enabled such works as Roker, Gibraltar and Dover to be carried out.

This reference to mechanical engineering draws attention to the subject of dredging. As before said, the ancients do not appear to have carried out any important deepening works, and there is a remarkable paucity of information as to any dredging machine, which, as a member of our Society, Mr. J. J. Webster, in a paper read before the Institution of Civil Engineers* is claimed to have been first used by the Italians or Dutch. The author would refer members to this paper and the discussion thereon as being one of the most instructive of many papers on this subject. In an equal degree with the construction of breakwaters the dredging of harbours has developed with the development of mechanical engineering. The latest development is that of suction dredging, which has rendered possible the improvement and maintenance of harbours which could not have been either improved or maintained economically in any other way, although a suction dredger to deal satisfactorily with mud does not exist. It is only necessary to mention in this instance the river Maas and the Mersey Bar. In the latter case, Mr. Webster, in his paper referred to, discouraged the idea of attempting to form a channel by dredging alone, and at that time, 1887, most engineers agreed with him. The remarkable success, however, of Mr. Lyster's work in deepening the bar is familiar to all engineers.

The cost of suction dredging is comparatively small. In the case of Ostend the author advised the contractors whom he represented to quote a price under 5d. per cubic metre, which included the deposition of material four miles out at sea, and at Port Said, where it had to be pumped ashore and delivered three-quarters of a mile off the site of the dredger, the price was under 8d. per cubic metre.

On this point it may be said that in most discussions on the cost of dredging by bucket ladder machines, the information as to low cost of dredging by Corporations such as the Tees and Tyne Commissioners has been taken with a considerable degree of

*In Proc. Inst. C.E., Vol. LXXXIX.

scepticism. The ascertained cost of lifting soft material and conveying it 10 to 12 miles worked out about 5d. per cubic yard, but this amount did not include interest on capital nor depreciation. A contractor doing the same work would have to add interest and depreciation, contingencies, establishment expenses, insurance and profit, which would bring up his price for similar work to something like 1s. 4d. per cubic yard.

When maintenance work is a permanent operation it is more economical for harbour authorities to do dredging themselves, but in cases where dredging once carried out will be naturally maintained it may be cheaper to contract for the work and thereby save a heavy expenditure upon plant. So much has of recent years been written on the subject of dredging that the author feels it unnecessary to deal at greater length with the subject. In addition to Mr. Webster's paper referred to, there is a quantity of detailed information as to appliances and cost of dredging and rock blasting in Mr. W. H. Wheeler's book "Tidal Rivers," published by Longmans & Co., and also in a paper by the author read before this Society on "Dredging in the River Ribble."

In addition to deepening of rivers and harbours by dredging they may be deepened by scour induced by training walls or groynes. The latter are not now used for deepening except in exceptional circumstances, as their deepening effect is local and there is a reactionary effect in silting up when the abnormal scouring effect ceases, they are however valuable in preventing the erosion of banks. Groynes were in use before longitudinal training walls. The late Mr. David Stevenson, of Edinburgh, gives the credit of the first introduction of low parallel training walls to Mr. James Walker, M. Inst. C.E., who used them on the Clyde, at Dumbarton, in 1836. In 1838, Mr. Stevenson introduced them on the Ribble, and in 1851 the cross jetties on the Tees, some of which were put down under the advice of Mr. W. A. Brooks, M. Inst. C.E., in 1846,* were cut down and longitudinal training walls substituted. Up till 1884, the Ouse, from Goole to its confluence with the Humber, was remarkable by the presence of groynes, which were abandoned when the Aire and Calder Navigation Company obtained powers for longitudinal training walls in 1884. These walls have resulted in a marked improvement of the channel without dredging.

The function of training walls is either to fix or deepen a channel or both. The bars of the Tyne and Tees have been projected into

* Proc. Inst. C.E., Vol. XC., page 346.

deep waters owing to induced scour by means of permanent works, and no dredging has been carried out on the bars of these rivers, although a large amount of dredging has been done between the walls inside the bars. In a paper read at the 1897 Engineering Conference of the Institution of Civil Engineers, the author concluded his remarks by expressing the opinion that "It is impossible to adopt "an absolute precept, but as a general principle it is probably right to "state that the ideal function of training works is to attain stability of "position, and when deepening is required it is desirable to provide it "by dredging."

The cost of training works depends entirely on position and the facilities for procuring stone. The cost per cubic yard of the North Training Wall in the Ribble, below Lytham, varied from 5s. to 8s. per cubic yard, according to the amount of quarry stone used, this stone was brought from North Wales in saddleback hoppers and discharged on the line of wall, being afterwards trimmed by hand. This was the method adopted by Mr. W. H. Bartholomew, M. Inst. C.E., on the Ouse walls with the same vessels which were afterwards used on the Ribble. The difficulty to be contended with in the construction of low training walls is not so much the force of the sea, as the danger of scour round the end of the wall during construction. During the construction of the Ribble wall referred to, as much as 15 feet depth of sand was in places scoured out, which had to be filled in with stone or clay dredgings.

A frequent but not a necessary result of the construction of training walls is accretion of sea sand or alluvial matter behind the walls. When a channel is merely maintained in position and not artificially forced in a direction contrary to nature the accretion may be so slight as to be inappreciable. This has been the case in the river Tees, where in 1883, thirty years after the construction of training walls, about three miles below the Middlesbro', cross sections taken by the author under the direction of his father, showed that there had been practically no accretion, and the deep pools on both the north and south sides of the channel behind the training walls are still there though probably of less depth. A contrary result may occur when a wall is designed to create an artificial channel. It is probable that the greatest factor in causing accretion of an estuary is reclamation about high-water mark. The line of high water is thereby pushed forward and deposit takes place at the part least affected by tidal action. There is at the present day a somewhat unreasoning prejudice against any reclamation of rivers or estuaries on the ground that the consequent

accretion decreases tidal volume, and results in depreciation of the navigable channel. When it is remembered that the sea coast of Holland has been projected for a great length into the sea by means of reclamation and with great benefit thereby to its navigable rivers, it is evident that reclamation can be used as an improving agent but should not be abused.

Judging from the results of reclamation at the mouths of the Maas and Scheldt as compared with the Cheshire Dee, the Ribble and the Tees, it seems reasonable to assume that rivers with large drainage basins may be improved by reclamation at their outlets, and cannot well be injured, and that portions of estuaries into which rivers of small drainage area debouch, may be reclaimed with advantage if well considered, provided that comprehensive lines of reclamation are first laid down.

In the natural order of things we now come to docks, and although some sort of finality in the construction of breakwaters and in the magnitude of dredging operations can be imagined, it would be rash to prophesy any finality in the dimensions of docks. Mr. A. G. Lyster has shown the author an interesting diagram of the length and tonnage of the largest steamships trading to Liverpool from 1883 to 1903 inclusive. The list starts with the "City of Rome," 500 feet long and 8144 tonnage, and finishes with the "Baltic," 709 feet 2 inches long and 23,876 tonnage. The new Cunarders will be 760 feet long and 87½ feet broad, the gross tonnage being 30,000. Two years ago the largest Graving Dock at Tranmere now under construction for Cammel, Laird & Co., was designed to be 840 feet long and of a depth over the keel blocks of 30 feet at H.W.O.S.T. It will be, when finished, 865 feet long and have a depth of 33 feet over the keel blocks. The width of the entrance is 90 feet, so that there will not be much to spare in docking the large Cunarders. It is evident that as regards the length and depth of large ocean steamers we have not yet arrived at a standing point of any long period, and that works designed for the accommodation of the largest vessels of twenty years ago are rapidly becoming out of date for the largest vessels of to-day.

Passing however from this question to the construction of modern docks, the most striking change in engineering practice is the extensive use of Portland cement concrete. This was first used in the main drainage works, London, and the Albert embankment in 1859.* In the extension of Chatham Dockyard in 1867 Portland

* Proc. Inst. C.E., Vol. XXII., page 266.
Proc. Inst. C.E., Vol. LXII., page 69.

cement was not mentioned in the specification, but was afterwards used to the exclusion of blue lias lime. In the construction of dock walls it was first used for foundation work and backing, next in the formation of the main body, the wall being faced with ashlar or brickwork above water level and coped with masonry, and finally is now largely adopted for the entire construction of the walls, the face and coping being composed of a richer proportion of cement. The main portion of the walls of the floating basin at Tranmere now being carried out is composed of concrete in the proportion of 1 part Portland cement to 8 parts gravel and broken stone, the facing of the walls and coping which is laid *in situ* is composed of 1 part cement to 4 parts fine gravel. The walls when not on rock are founded in rows of bearing piles 8 feet apart, not connected by walings either crossways or longitudinally. The old fashioned plan of connecting bearing piles by cross waling and constructing thereon a timber platform usually of deals about 3 inches thick seems to have been entirely discontinued, and in the case of concrete, which as soon as it was set entirely does away with the function of walings and platforms, they are entirely unnecessary.

The use of Portland cement concrete has brought about the Monolithic system of foundations for dock walls in places where the strata is not favourable for ordinary bearing piles. The principal of the Monolith is not new, as wrought or cast-iron cylinders sunk by manual excavation under air pressure and weighted on top, have been used for many years. The Monolithic system has been adopted at Bristol, Cork, Glasgow, Heysham, and for a portion of the new river wall at Tranmere, now being carried out by Mr. A. G. Lyster.

One of the most recently finished works is that of Heysham Harbour. Mr. George Abernethy, M. Inst. C.E., the joint engineer for the works, in company with the late Mr. J. A. McDonald, has kindly referred the author to the detailed information published in "Engineering," August 5th, 12th and 19th.

The Monoliths under the walls are 24 feet long by 17 feet wide, on the wall face, they are constructed on a wrot-iron hollow casing, the inner plating of the casing being spaced 2 feet from the outer and concrete filled in between. On this composite shoe, brick walls, 4 feet in thickness, are constructed with 3 feet transverse walls, thus leaving cores 6 feet by 9 feet, which were filled in with 6 to 1 concrete for a height of 15 feet from the bottom, then a varying quantity of sand filling, and finally 9 to 1 cement concrete to the upper level of the brickwork. There is a width of 3 feet between each Monolith,

and it was found that they could be sunk with greater accuracy by proceeding with alternate Monoliths, afterwards filling in the spaces with the next series. There was an outer coffer dam at Heysham, but the ground over the greater portion of the walls was so bad that enormous expense would have had to be incurred in trenching and pumping, so that failing the use of Monoliths subsidiary coffer dams would have had to be constructed.

Another application of Portland cement concrete is that of fortified or reinforced concrete as used in the foundations of quays and warehouses when the ground is unstable. Reinforced concrete is a combination of Portland cement and iron or steel rods or sections. There are many patents in connection with the detail of the matter, but the broad principle is that the rigidity of the concrete is fortified by the toughness of the steel, or *vice versa*. As regards fortified concrete piles, they are no doubt valuable and economical when used in soft strata, but if required to be driven through tough, not to say hard ground, their usefulness has yet to be proved. It does not strike one that a small plaster of concrete surrounding an iron section is better than a slight increase of the iron section, and further, the value of concrete arises in the mass or monolith. The opinions set forth are those of the author, who has not used any of the patent processes connected with reinforced concrete, and the value of those opinions must be gauged accordingly.

The author regrets that the title of this paper has involved a lengthy retrospect. He has endeavoured to avoid detail, as there is so much to be obtained from the records of this Society, and from the Minutes of the Proceedings of the Institution of Civil Engineers. Therefore reference to floating pontoon docks, the approved dimensions of graving docks, the mechanical appliances for working of dock gates and pumping out of graving docks, are not touched upon.

In conclusion, the author would like to observe that the period preceding and immediately anterior to the Christian era was comparatively conspicuous for harbour works, and that afterwards there was a lapse of practically 1300 years of stagnation until the reign of King Henry VII.

DISCUSSION.

Mr. Thomas Duncanson said—We have listened to a very valuable paper, which covers such a large area of ground that it is somewhat difficult for us to discuss it properly in the little time that is left to us. Mr. Duncanson

There are several points which one would like to mention. One is the question of dredging, and especially suction dredging. I suppose that the results obtained by Mr. Lyster, at Liverpool, have practically revolutionised the entrance into Liverpool, and the information which the author has given us as to the cost of dredging, &c., is of considerable interest.

With regard to accretion, I have some recollection of seeing it stated that the explanation of the absence of accretion in the Tees was that the velocity of the current being low, there is not the same tendency to carry matter in suspension in the water as if it were higher, and therefore the accretion is not so considerable as in estuaries where the current is higher.

Then, referring to reinforced concrete, the author says he has not used it himself. We see it, however, extensively used about the Liverpool docks and elsewhere in the city, and it is undoubtedly a method of construction which has come to stay.

It would be interesting to know to what extent danger exists of reinforced concrete going to pieces owing to the action of rust. It appears to me that if water comes in contact with the iron there would be a risk of rust setting up and splitting the concrete. This is a matter, however, in which experience is the only guide.

Mr. Somers H. Ellis said—I should like to express my thanks to the author for his very instructive paper, chiefly, perhaps, for the information he gives us as to work that has actually been carried out; partly from his own experience, and partly from that of other Engineers. Harbour Engineering seems to me to be one of the most fascinating branches of Engineering, because here, more than elsewhere, theoretical knowledge goes for very little, and practical experience counts for a great deal; and to those of us who have not had the opportunity for wide experience, it is most valuable to hear that of others who have. Mr. Ellis

Mr. Ellis One point which illustrates this difference is one which the author has mentioned—as to whether the faces of breakwaters should be vertical or battered. The old practice was to make them battered or curved, with a smooth face, so that the force of the waves might be checked gradually. That would seem to be, theoretically, the right course to take; but I think that the modern practice is to make them vertical, or nearly so; and often intentionally rough on the outside, in order to prevent waves from sliding up the face and breaking over the parapet. I remember seeing last Summer a small harbour on the coast of County Down, where the protecting breakwater had a smooth battered face of masonry, with a smooth apron of concrete extending outwards from the base of the wall. The consequence was that waves were led up this slope and right over the top of the wall; and I was told that in rough weather vessels had to leave the harbour instead of coming in. Apparently, also, a considerable amount of shingle had been carried into the harbour by the same means.

I should like to ask the author if the training walls on the Tees had actually no effect on the channel between the training walls. He says that dredging was subsequently carried on in the channel between these, though not on the bar. I suppose the training walls would ensure a greater current, and thus more scour, towards the bar, if not higher up the river.

As to the width of the larger graving dock at Tranmere—which the author mentioned as being 90 feet—it is 90 feet over the sill; but, owing to the batter of the walls, which is 1 in 7, there is actually an effective width of about 94 feet, at the level of the greatest widths of vessels.

Mr. Hope Mr. Alaric Hope said—In reference to Mr. Duncanson's remarks about reinforced concrete it might be interesting to the Society to know that I have lately examined some Hennebique reinforced concrete piles which had been driven some seven years ago at Southampton to form what is known as the Woolston Jetty.

The piles were 12 inches square and contained four steel bars of 1 inch diameter, spaced about 7 inches apart centre to centre, and connected together at intervals. These metal bars therefore had a covering of concrete only about 1 inch thick. A stump or end of a pile which, at the time of the construction of the jetty, had been cut off and left lying on the foreshore was broken open and examined.

The surfaces of the steel bars were found to be of a bluish colour and were perfectly preserved.

These piles, the tops of which were above high water level, were the first of the kind driven in England: they appeared to be in excellent condition, and a few rust stains observable were due to the connecting wires having been brought too near the surfaces of the piles and so having insufficient protection. Mr. Hope

I was informed that the concrete had been made of Portland cement and Southampton gravel in the proportions of 1 to 5.

I may say that there are some interesting Harbour Works now in progress at Zeebruzze in Belgium.

Two parallel curved walls are being constructed in the open sea upon a soft bottom, and the method adopted is that of constructing in dry dock huge tanks or caissons in reinforced concrete which are towed out, sunk in position by the admission of water at slack tide, and subsequently filled with concrete.

The displacement of these caissons when afloat is as much as 1500 tons.

They are founded on tipped rubble, the surface of which is roughly levelled by divers.

The space between the two parallel walls is to be filled up to form accommodation for roads, sheds, railway lines, &c., &c.

At the Gibraltar Harbour Works, now approaching completion, the deep water moles were built with concrete blocks weighing up to about 30 tons each laid obliquely in the manner adopted at Colombo.

They were set upon a foundation of rubble, the upper surface of which was about 30 feet below water level.

In the construction of the Commercial moles a trench was first dredged, which was filled with 5 to 1 concrete deposited under water and very carefully levelled with darbies by divers. On the foundation thus formed the walls were built of interlocking concrete blocks shaped something like cement briquettes made for tensile testing. These blocks were made of 4 to 1 concrete at least 28 days before they were set, having been removed from their wooden moulds after setting four days. They were made with great accuracy so as to fit one into the other and bear evenly without cement or mortar jointing.

Above water level the walls were finished in mass concrete with coursed limestone ashlar faces and granite copings. The water being very clear and the currents slight the conditions were favourable for the employment of divers, and it was found possible to construct good level foundations for the concrete blocks under water. One diver could set as many as 30 to 35 blocks in a day.

Mr. Fowler

Mr. A. F. Fowler, in reply, said—In answer to Mr. Duncanson, the author would remark that the tidal velocity in the River Tees is small and there is also comparatively little alluvial matter in suspension. These two features, coupled with the fact of the training walls being merely a protection for an existing channel, and therefore not interfering to a great extent with the natural regime, no doubt explain the small accretion which has taken place.

In reply to the question of Mr. Ellis, there is no doubt that the training walls would have some deepening effect, but to a much greater extent deepening was effected by dredging. No dredging was carried out on Tees Bar. This was lowered as a result of the construction, first, of the South Gare Breakwater, afterwards assisted by the Northern Breakwater. These structures concentrated the flow of tidal water passing in and out of the estuary.

The author cannot, as already stated, say much as to the use of reinforced concrete. In harbour work, the use of old rails or chains embedded in concrete masses gives a very strong construction, but this is not what has come to be known as "reinforced concrete," which is more as described by Mr. Alaric Hope in the case of Woolston Jetty at Southampton. In this case the proportion of steel to concrete is a very large one. The author thinks that at Southampton the piles would be very easily driven, and therefore the shattering of the concrete implied in his remarks, and probable rust, as mentioned by Mr. Duncanson, would not occur. In the construction of the platforms of quays and floors of warehouses there is of course no doubt as to the value of the combination of steel and concrete.

Mr. Ellis, in referring to the faces of breakwaters, states that the curved face would seem to be theoretically correct. That depends upon what the breakwater has to do. The curved face, one might say, is good for the breakwater, but possibly, as Mr. Ellis instances, bad for the harbour. This possibility no doubt has led to the modern practice of presenting a "straight front" to the action of waves.

LIVERPOOL ENGINEERING SOCIETY.

THIRTY-FIRST SESSION.

ANNUAL GENERAL MEETING—26TH APRIL, 1905.

FRANK E. PRIEST, M. Inst. C.E.

PRESIDENT, IN THE CHAIR.

The Election of Council and Officers for the ensuing Session resulted as follows:—

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J. RENEY SMITH, M.I. Mech. E., M.I.N.A.

Vice-Presidents—

A. F. FOWLER, M. Inst. C.E., M.I. Mech. E.

THOMAS DUNCANSON, M. Inst. C.E.

Members of Council—

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P. NOEL BOSCAWEN, Assoc. M. Inst. C.E.
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Liverpool Engineering Society,

ROYAL INSTITUTION, COLQUITT STREET.

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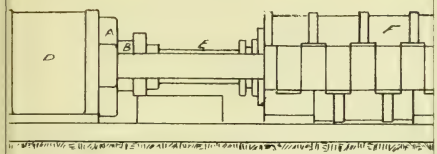

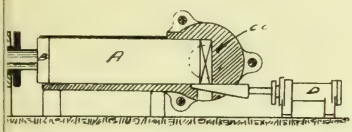

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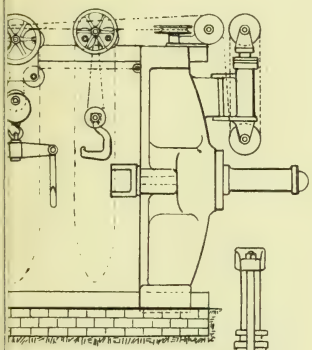


FIG 24

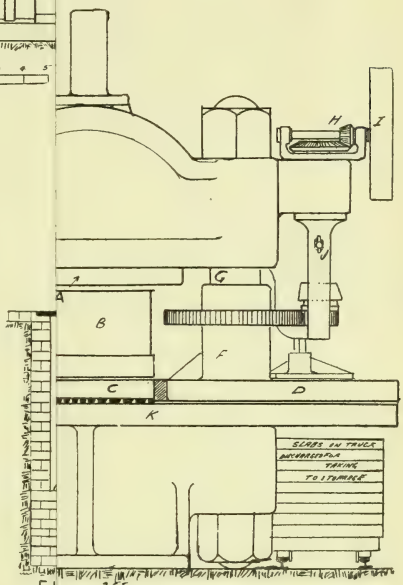


FIG 26

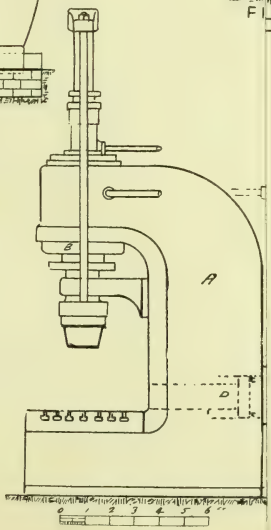
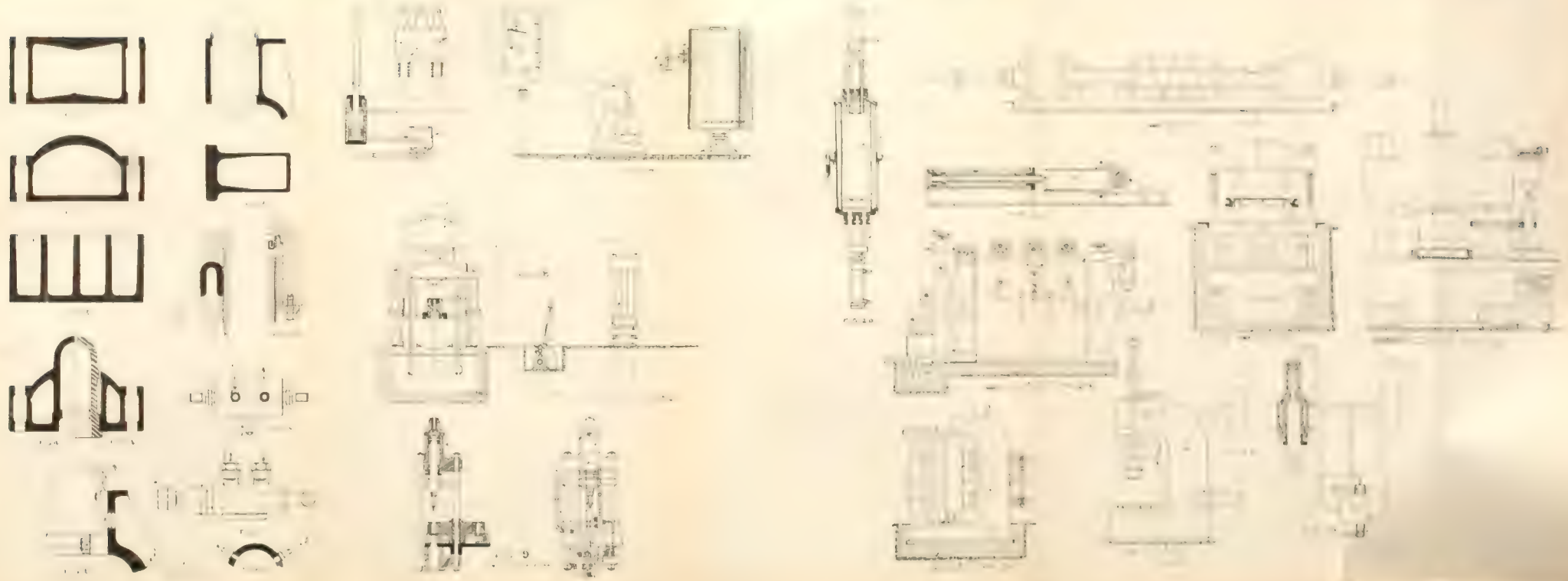
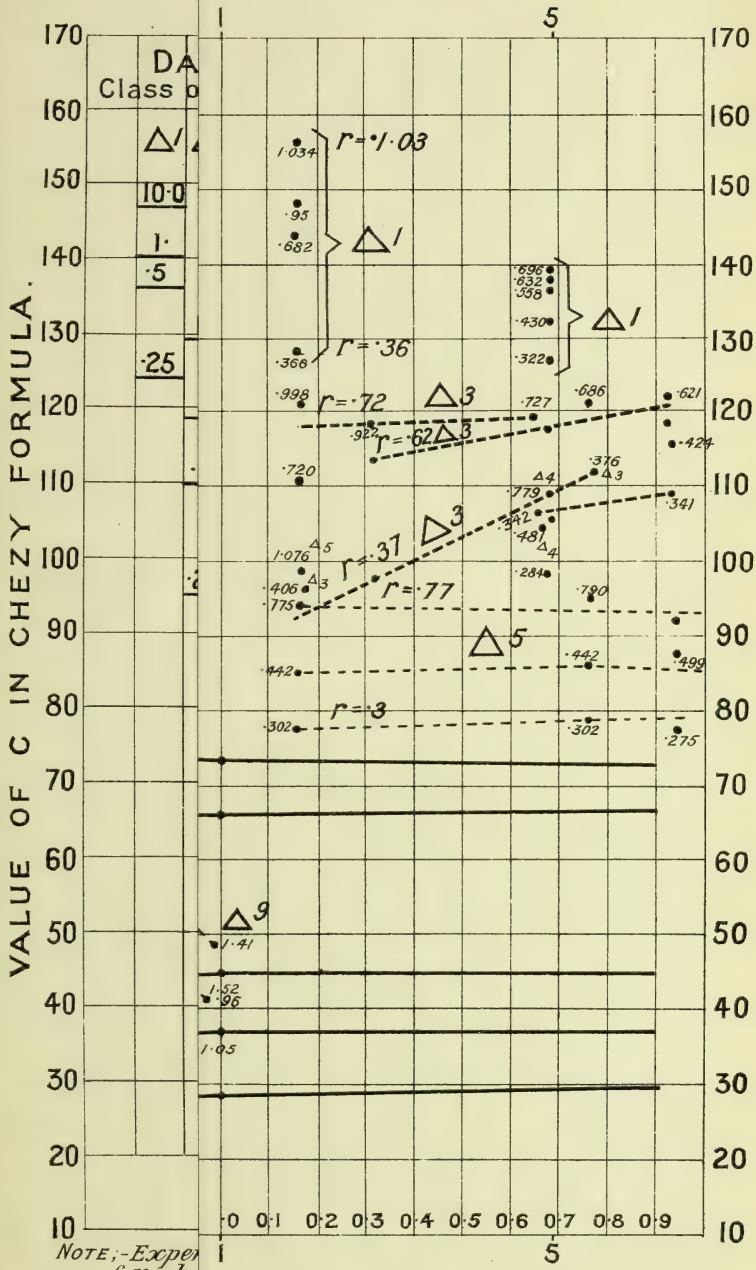


FIG 27





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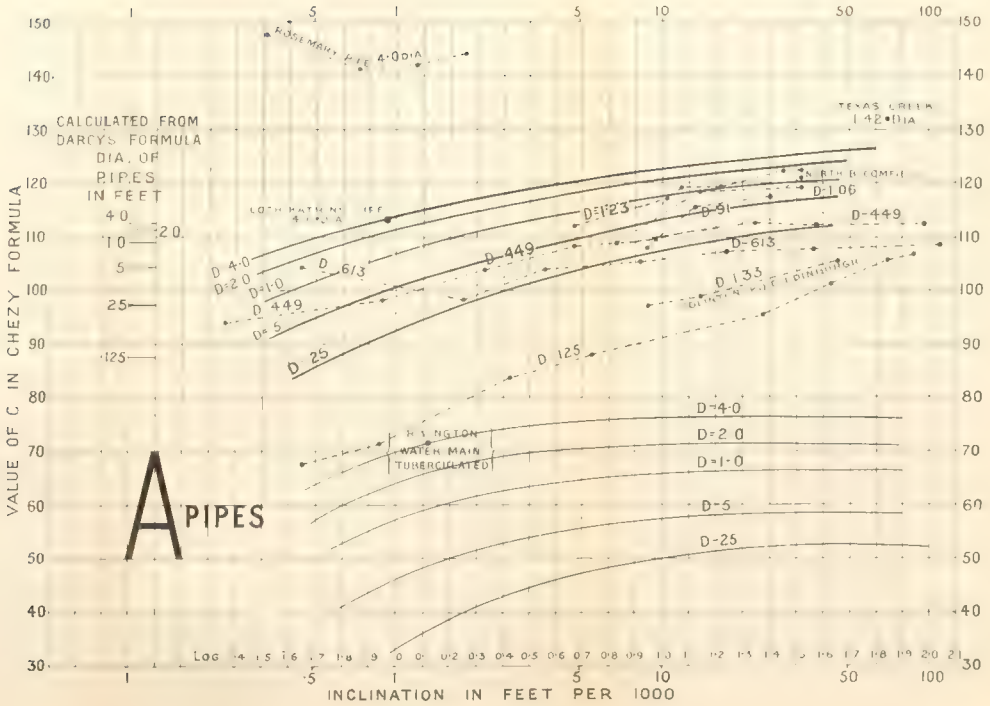
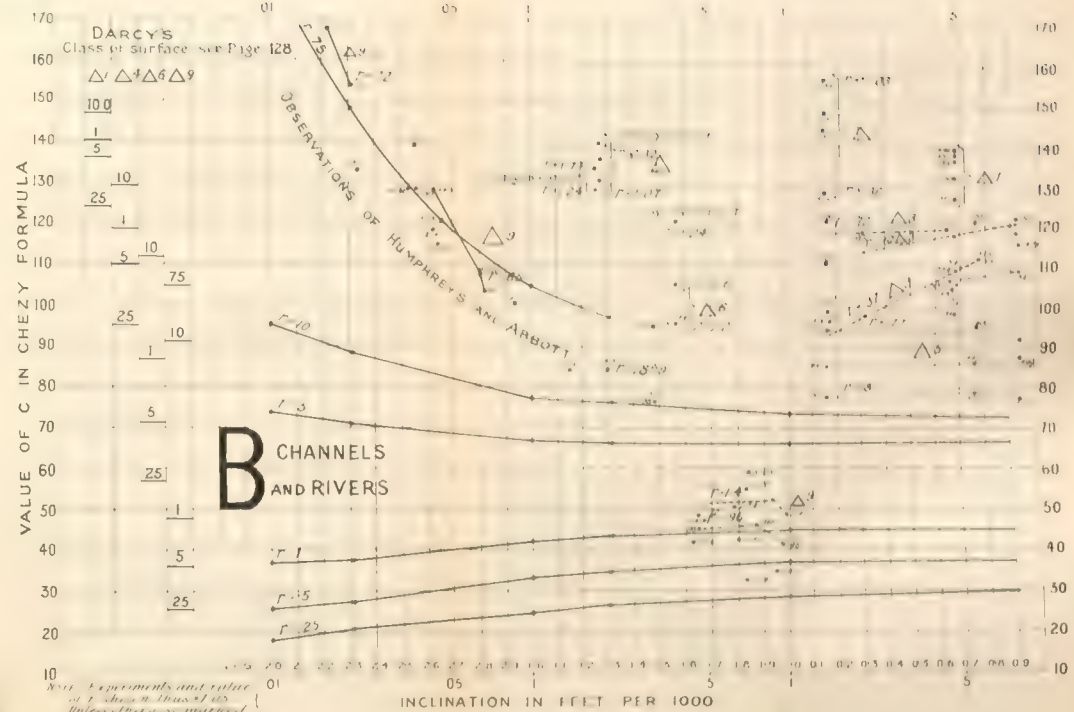

A PIPES
CALCULATED FROM DARCY'S FORMULA
DIA. OF PIPES IN FEET
VALUE OF C IN CHEZY FORMULA
INCLINATION IN FEET PER 1000
ROSEMARY PIPE 4·0 DIA
TEXAS CREEK 1·42 DIA
WASHINGTON WATER MAIN TUBERCULATED
D=4·0
D=2·0
D=1·0
D=5
D=25
D=1·23
D=0·91
D=1·06
D=449
D=613
D=1·35
D=125


DARCY'S
Class of surface see Page 128
OBSERVATIONS OF HUMPHREYS AND ABBOTT
B CHANNELS AND RIVERS
VALUE OF C IN CHEZY FORMULA
INCLINATION IN FEET PER 1000

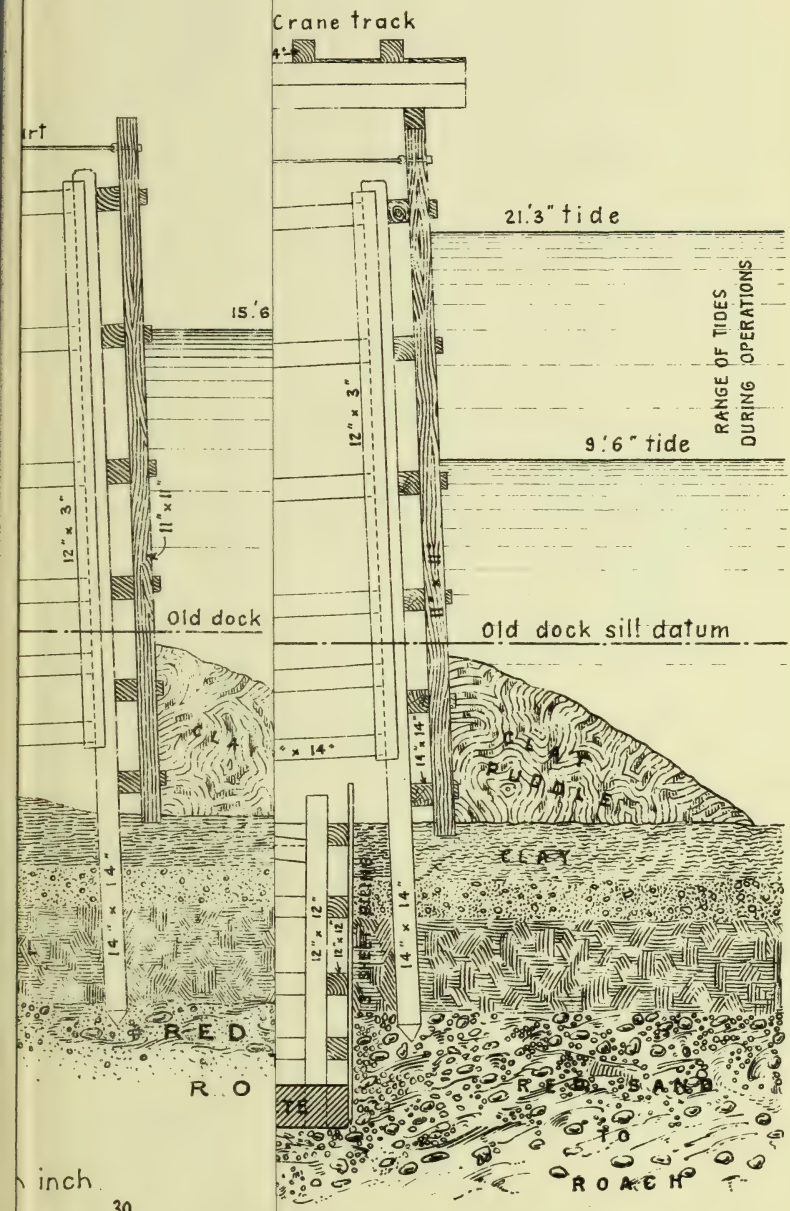

Crane track
21.'3" tide
15.'6
RANGE OF TIDES DURING OPERATIONS
9.'6" tide
12" × 3"
11" × 11"
Old dock
Old dock sill datum
14" × 14"
CLAY
RED
R O
TE
RED SAND
ROACH
inch
30

FIG 1

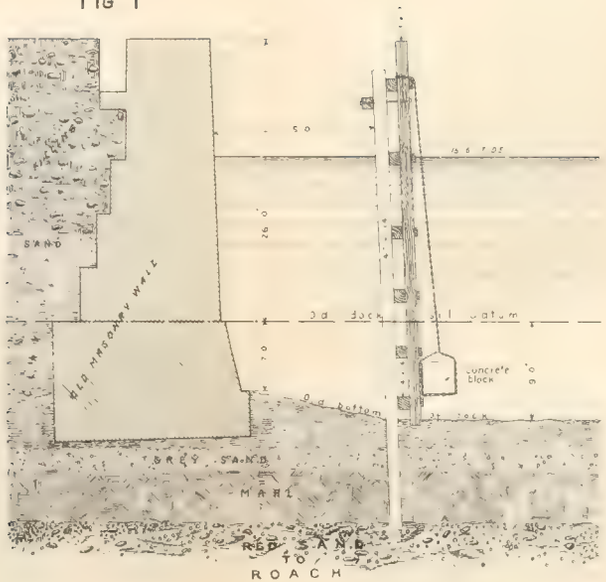


FIG. 2

FIG. 3

Scale ~ 10 feet to an inch

F' 10 5 0 0 20 30 40 50 F'

FIG. 7

G. 6

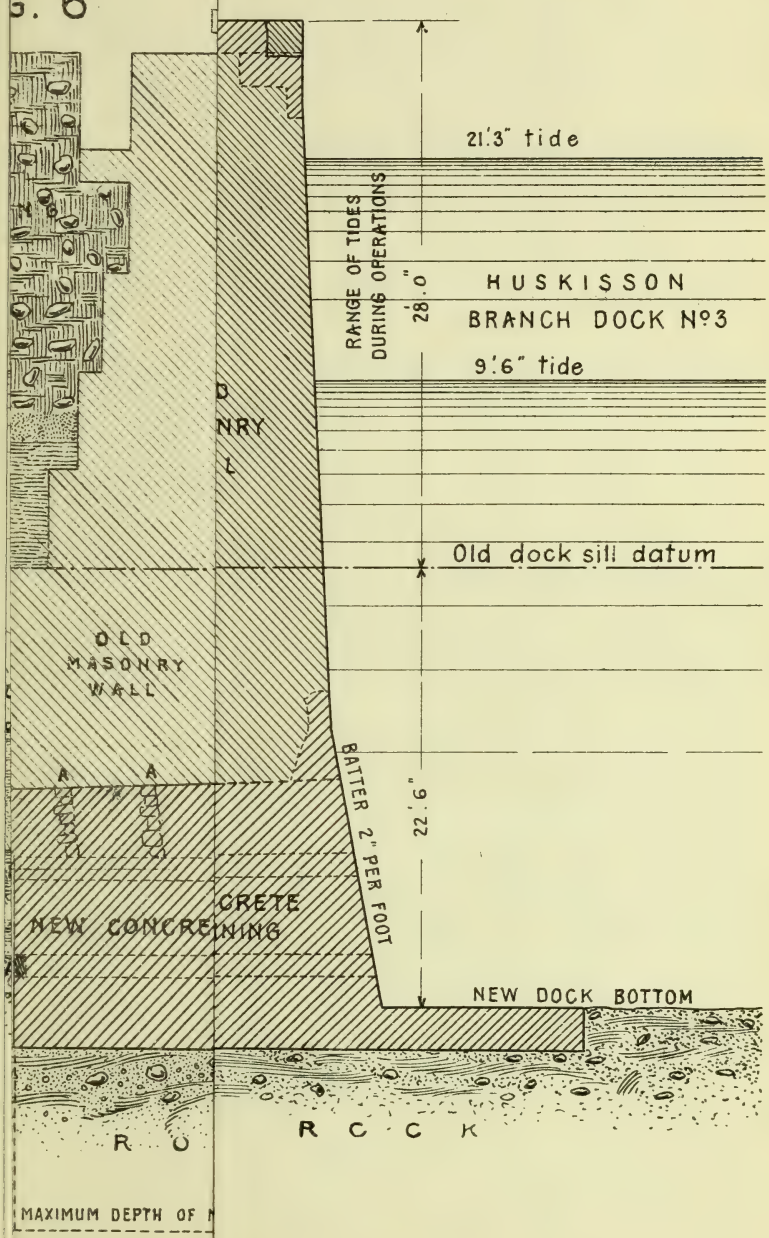

21.'3" tide
RANGE OF TIDES DURING OPERATIONS
28.'0"
HUSKISSON
BRANCH DOCK Nº3
9.'6" tide
D
NRY
L
Old dock sill datum
OLD
MASONRY
WALL
A
A
22.'9"
BATTER 2" PER FOOT
CRETE
NEW CONCRETE LINING
NEW DOCK BOTTOM
R O
R C C K
MAXIMUM DEPTH OF

Fig. 4

Fig. 5

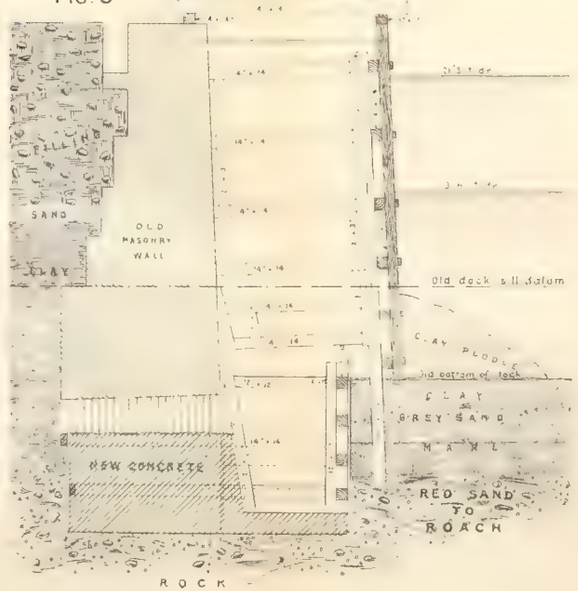


Fig 6

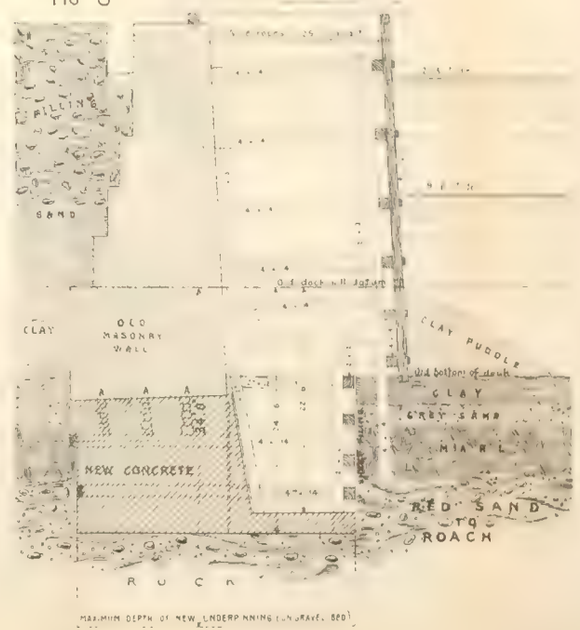


Fig. 7

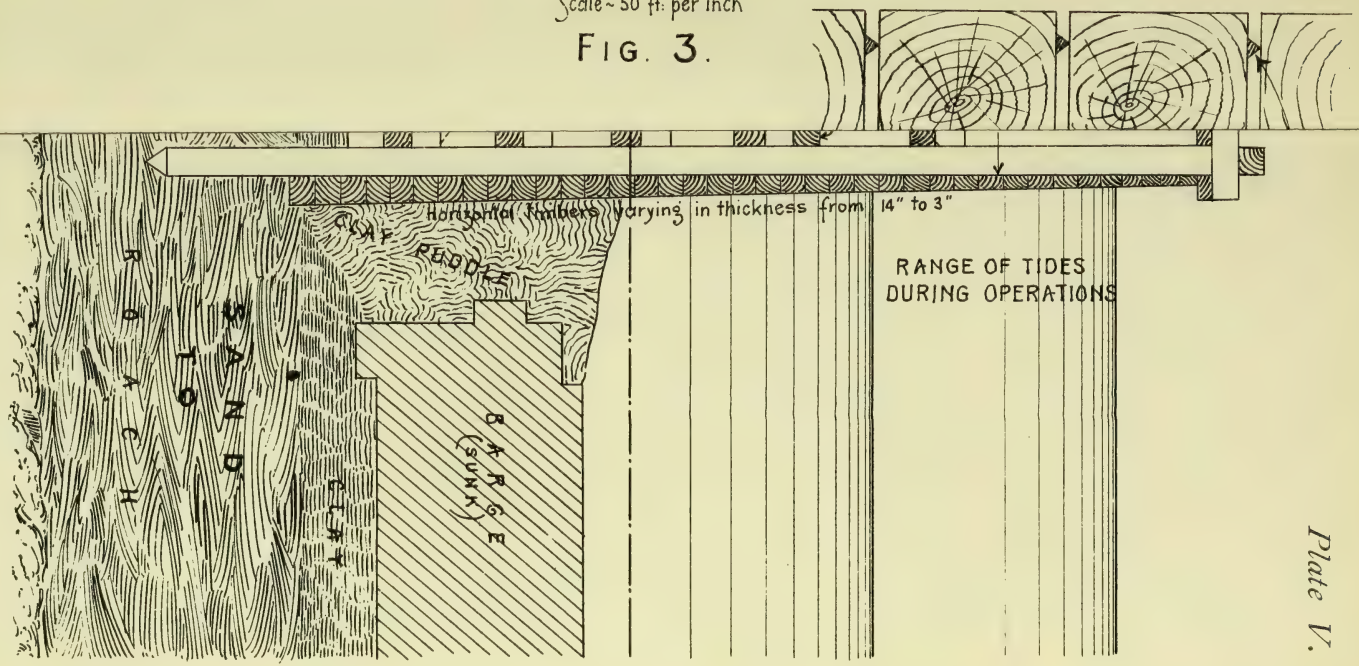
Scale ~ 10 feet to an inch

FT 0 5 10 20 30 40 50 FT

PLAN OF THE BOX DAM

Scale ~ 50 ft. per inch

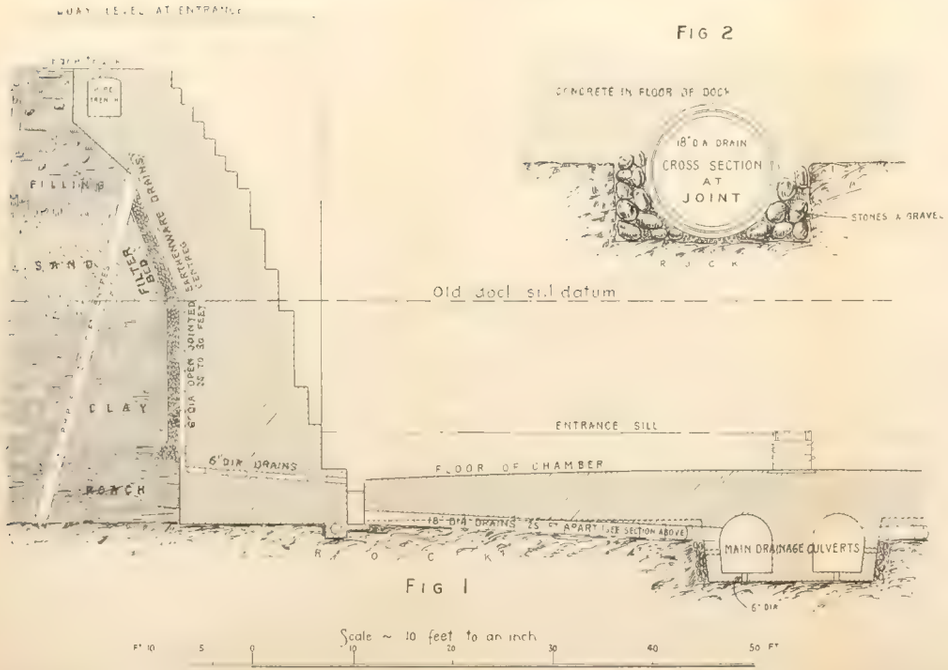
FIG. 3.

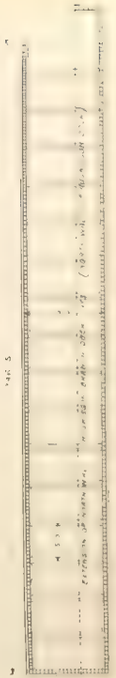


G. 4.

30 FT

Plate V.


QUAY LEVEL AT ENTRANCE
FIG 2
CONCRETE IN FLOOR OF DOCK
18" DIA DRAIN
CROSS SECTION AT JOINT
STONES & GRAVEL
ROCK
FILLING
SAND
FILTER
DRAINAGE
6" DIA OPEN JOINTED SERVICE PIPES 22 TO 30 FEET
CLAY
ROCK
Old dock sill datum
ENTRANCE SILL
FLOOR OF CHAMBER
6" DIA DRAINS
18" DIA DRAINS 25 FT APART (SEE SECTION ABOVE)
MAIN DRAINAGE CULVERTS
6" DIA
ROCK
FIG 1
Scale ~ 10 feet to an inch
FT 10 5 0 10 20 30 40 50 FT


PLAN OF THE BED DAM
FIG 3

Yellow Pine
1½" V Fillers
FIG. 5.

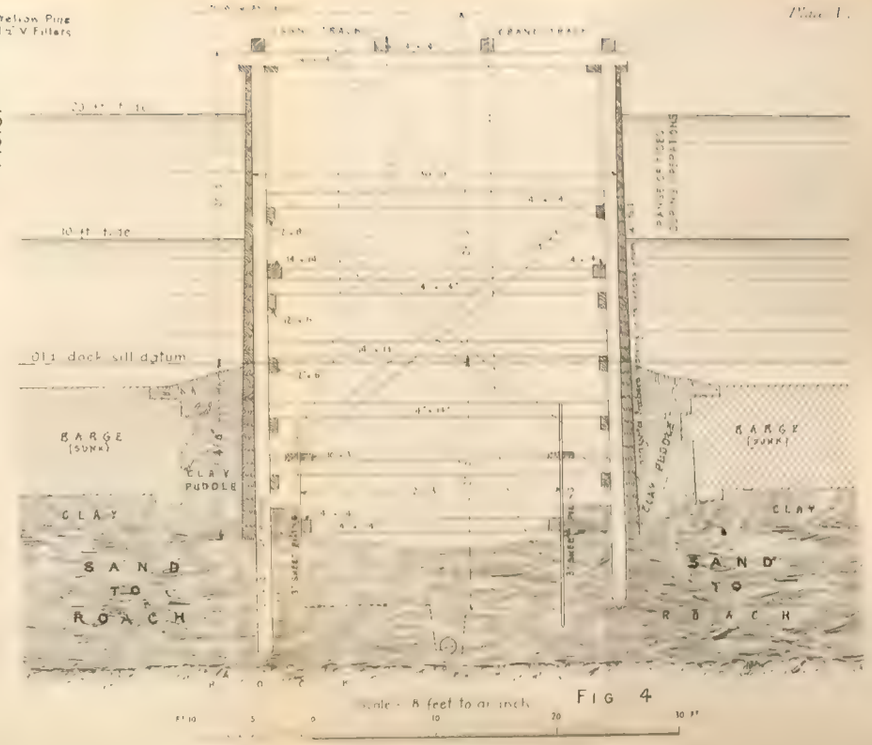
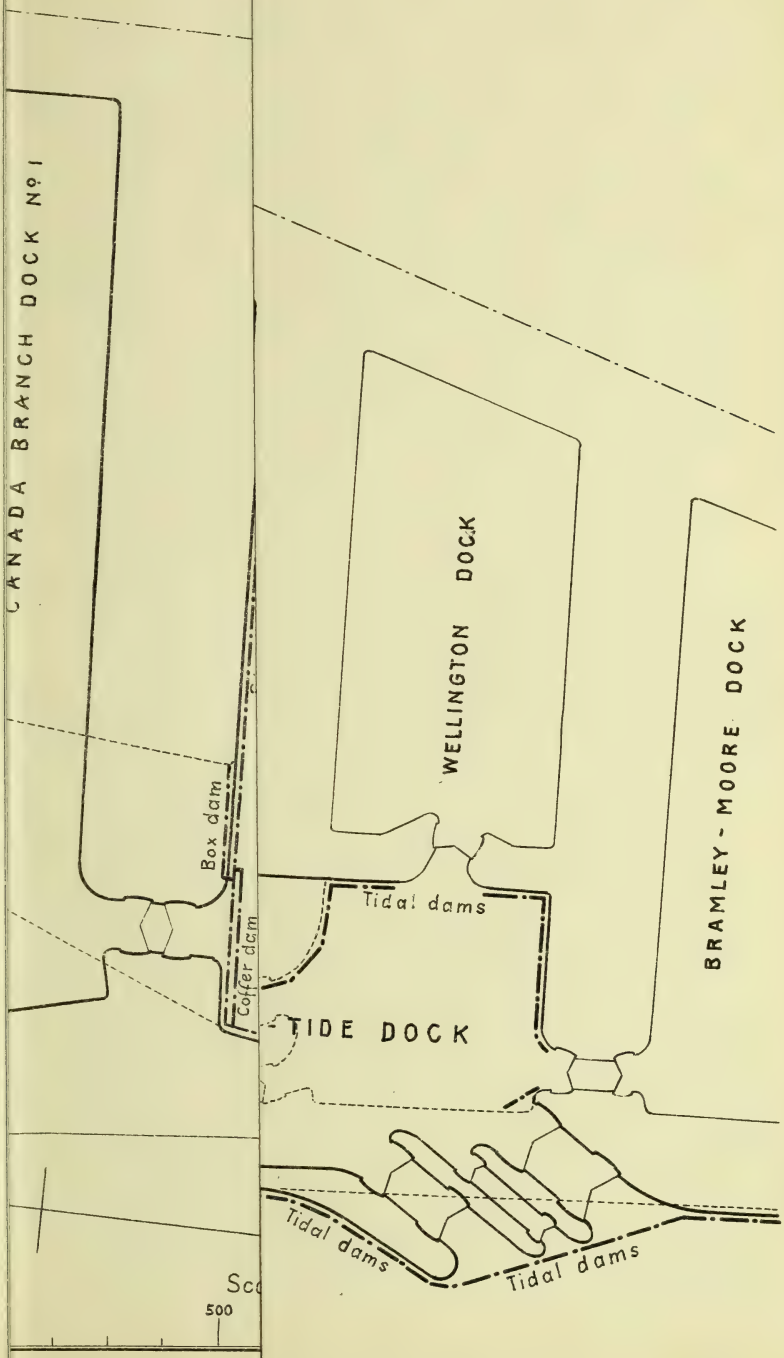
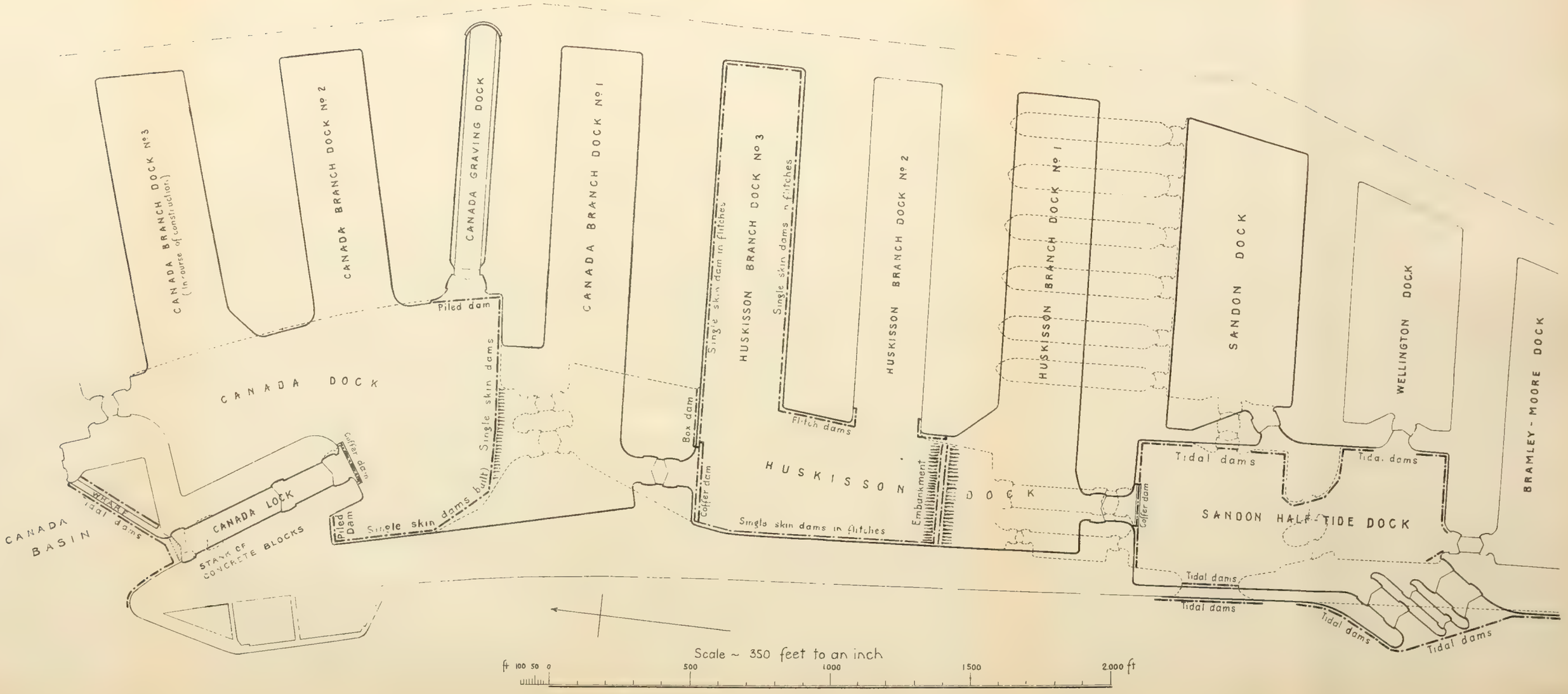

CRANE TRACK
Old dock sill datum
BARGE (SUNK)
CLAY PUDDLE
CLAY
SAND TO ROACH
CLAY FLOORS
BARGE (SUNK)
CLAY
SAND TO ROACH
Scale - 8 feet to an inch
FIG 4
FT 10 5 0 10 20 30 FT

Plate VI.


CANADA BRANCH DOCK No 1
Box dam
Coffer dam
WELLINGTON DOCK
Tidal dams
TIDE DOCK
BRAMLEY-MOORE DOCK
Tidal dams
Tidal dams
Sc
500


CANADA BRANCH DOCK No 3
(In course of construction.)
CANADA BRANCH DOCK No 2
CANADA GRAVING DOCK
CANADA BRANCH DOCK No 1
HUSKISSON BRANCH DOCK No 3
HUSKISSON BRANCH DOCK No 2
HUSKISSON BRANCH DOCK No 1
SANDON DOCK
WELLINGTON DOCK
BRAMLEY-MOORE DOCK
CANADA DOCK
HUSKISSON DOCK
SANDON HALF TIDE DOCK
CANADA BASIN
CANADA LOCK
WHARF
STAKE OF CONCRETE BLOCKS
Piled dam
Single skin dams
Single skin dams (built)
Coffer dam
Piled Dam
Tidal dams
Single skin dam in flitches
Single skin dams in flitches
Flitch dams
Box dam
Embankment
Scale ~ 350 feet to an inch
ft 100 50 0
500
1000
1500
2000 ft

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12. École d'application du Genie Maritime, Paris
13. Engineers' Club of Philadelphia
14. Engineering Society Western Pennsylvania
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16. Incorporated Gas Institute
17. Institute of Marine Engineers
18. Institution of Civil Engineers
19. Institution of Electrical Engineers
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28. Manchester Literary and Philosophic Society
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30. Midland Institute of Mining, Civil a Mechanical Engineers
31. Mining Institute of Scotland
32. North-East Coast Institution of Engineers and Shipbuilders
33. North of England Institute of Mini and Mechanical Engineers
34. North-Western Sanitary Inspecto Association
35. Philadelphia Commercial Museum
36. Royal Institution of Cornwall
37. Royal Philosophical Society of Glasg
38. Royal Physical Society of Edinburgh
39. Smithsonian Institution
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57. "Mechanical Engineer"
58. McGill University, Montreal
59. Patent Office Library
60. Society of Arts
61. University of Minnesota

Total Number of Transactions exchanged with other Societies ...	46
" " " presented to " " ...	15
Total ...	61

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